RESEARCH INVESTIGATIONS ON PHOTO FACSIMILE TRANSMISSION TECHNIQUES

REPORT NO. 3

THIRD QUARTERLY PROGRESS REPORT

1 JANUARY 1963 THRU 31 MARCH 1963

CONTRACT NO. DA36-039 sc-90862

DEPARTMENT OF ARMY PROJECT NO. 3A99-12-001

(U.S. ARMY ELECTRONICS MATERIAL AGENCY)
(FORT MONMOUTH, NEW JERSEY)

REPORT NO. 25,083

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8 July 1963

Ref: 283/885/2877

Gentlemen:

Subject: Photo Facsimile Transmission Techniques
Contract No. DA36-039 SC-90862
Third Quarterly Progress Report

1. In accordance with Contract No. DA36-039 SC-90862 The Third Quarterly Progress Report is being forwarded to you.

2. This report covers the period from 1 January 1963 through 31 March 1963.

THE MARQUARDT CORPORATION

Thomas G Bek

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TGB:WH:bg

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RESEARCH INVESTIGATIONS ON

PHOTO FACSIMILE TRANSMISSION TECHNIQUES

Report No. 3

Third Quarterly Progress Report

1 January 1963 thru 31 March 1963

Contract No. DA36-039 SC-90862

Signal Corps Technical Requirements No. SCL-4362A

dated 2 February 1962

Department of Army No. 3A99-12-001

Objective: A research investigation leading to the development of techniques useful in the design of a facsimile scanner which shall be capable, upon command, of capturing an optical image, scanning it with high resolution and storing it or directly transmitting it via radio to a facsimile recorder.

Report prepared by

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THE MARQUARDT CORPORATION

VAN NUYS, CALIFORNIA

Report No. 25,083

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

PURPOSE

The theoretical and experimental research study under this contract is directed toward investigating pertinent materials and components with the purpose of evolving a new design concept for an advanced image transducer. Major emphasis in the study is on (1) photosensitive material having the properties of storage and erasure, (2) component techniques for achieving high resolution, fast and accurate readout of the stored information and (3) image transducer system analyses. The ideas, techniques and data evolved in the study will be applied to the generation of a design recommendation for the construction of a feasibility model of an advanced image transducer.

ABSTRACT

The major effort during the third quarterly period on advanced photo facsimile transmission techniques has been to experimentally demonstrate the feasibility of the ferrotron concept, and to explore possible means of matrix readout for the ferrotron. In addition, work was continued on system analysis, component technique investigations and material studies.

In the area of image transducing system analysis several methods of combining the exposure, readout and erasure functions of the image transducer into an integrated system are described. Special consideration is given to systems employing either the ferrotron, the polatron or the daptron type of storage element. The comparative analysis must await specific data obtained in material experiments.

A promising concept for an image transducing element, the polatron, has been evolved. This concept is based upon the persistance of polarization in a double activated phosphor. It is characterized by exceptionally fast readout and erasure responses.

Several matrix scanning techniques for the electronic readout of a stored image have been investigated. It is shown that a matrix using ferrotron elements overcomes the isolation limitations inherent in matrix arrangements. Furthermore, with the ferrotron element a "3-dimensional switching" concept can be made possible resulting in an appreciable savings in electronic circuitry and components.

The feasibility of the ferrotron concept was experimentally demonstrated. For this purpose a test setup with a single ferrotron element was constructed. It was shown that the device responded to an exposure time of less than 20 milliseconds, that the signal could be retained for longer than a minute and that the element could accept a subsequent exposure immediately after readout.

As a result of the literature search, materials exhibiting properties associated with the ferroelectric and the persistent internal polarization phenomena are listed. Barium titanate and zinc cadmium sulfide are for their respective phenomena the most promising materials for the formation of an image transducer element. Experiments are required to establish detailed material performance data.

The Experiment to develop a transparent synthetic form of hackmanite was continued. Although progress has been impeded by unexpected hot-press equipment trouble, increasingly transparent samples have been prepared, some of them as thin as 1/16 inch. An Experimental investigation was initiated to determine the phototropic properties of semicarbazones. Since the absolute sensitivities of these compounds were found to be very low, further work along these lines was discontinued.

PUBLICATIONS, LECTURES, REPORTS AND CONFERENCES

A. PUBLICATIONS:

None

B. LECTURES:

None

C. REPORTS:

"Research Investigations on Photo Facsimile Transmission Techniques", Monthly Progress Summary, January 1963, Reference Letter 283/885/2558, dated 5 February, 1963.

"Research Investigations on Photo Facsimile Transmission Techniques", Monthly Progress Summary, February 1963, Reference Letter 283/885/2605, dated 5 March 1963.

D. CONFERENCES:

None

I. INTRODUCTION

In order to advance the state-of-the-art in facsimile transmission techniques, it is necessary to evolve new image transducing concepts through an applied research study. Toward this end, effort during the first three quarters has been applied in three areas: (1) system analysis; (2) component research; (3) materials study. As the work progressed, the least promising materials and techniques were eliminated, resulting in a systematic narrowing of the possible approaches, and in formulation of a specific design plan.

Under the category of system analysis, it is necessary to define the desired performance characteristics of image transducer systems. Studies of scene composition and of parametric interrelationships were carried out during the first quarter, and a survey of the state-of-the-art in existing image transducing systems was made during the second quarter. As a consequence of the studies and survey, insight was gained into theoretical and practical image transducer performance limitations. During the third quarter, methods were evolved of employing the more promising image retaining materials in a complete image transducing system. All of the above investigations will be useful in establishing design configurations for the advanced system.

An image transducer for advanced facsimile transmission system requires components capable of regenerative image retention and readout. The requirement for retention comes about due to the presumed relatively low transmission bandwidth. A further system requirement is that the storage medium for image retention be capable of erasure in order to allow the storage of a new image after a prior image has been retrieved. Recently, new developments have been made in components capable of image retention and erasure. Of these, one which shows great promise for application in an advanced image transducer is the ferrotron element (a combination of a ferroelectric and a photoconductor material). This element was incorporated into a test setup and preliminary experiments were made during the third quarter to establish read-in, readout and erasure capabilities. For image readout, a matrix switching method is desirable to realize the advantages of a completely solid state image transducing system. Other components which are of interest involve the use of double-activated phosphors (either in the normal mode of operation or in the persistent internal polarization mode of operation). Further experiments will yield data with which the performance characteristics of the transducer methods can be evaluated for comparison.

The choice of an image transducing material is a function not only of characteristics of the material, but also of the image transducing system configuration. During the first quarter, it was found that the information obtained from the literature search was frequently descriptive and lacked quantitative data. It was realized during the second quarter that experimentation would be required which is confined to the most promising materials. Experiments were, therefore, initiated to prepare a synthetic form of hackmanite with characteristics superior to those found in the naturally-occurring form. No significant results have been obtained. Further experimentation is required to explore the suitability of other materials in a search for the ultimate image transducing element.

II. SYSTEM ANALYSIS

A. SUMMARY

In order to take advantage of the studies of scene composition and of parametric interrelationships which were carried out in the first quarter, and of the state-of-the-art survey of existing image transducers which was carried out during the second quarter, it was decided that effort should be applied during the third quarter in analyzing the image storage and retrieval cycle (exposure, readout, and erasure) utilizing the following two image retentive devices:

a) The ferroelectric-photoconductor combination (Ferrotron)

b) The double-activated phosphor (Daptron)

A third promising device, the Polatron, has been evolved during this quarter. A survey and evaluation of image storage materials and methods indicated that the materials listed above are those showing most promise for application in an advanced image transducer. As a consequence of this effort several promising system configurations were evolved.

B. IMAGE STORAGE AND RETRIEVAL CYCLE

In the study of the image storage and retrieval cycle of an image transducing system, the exposure, readout and erasure functions of the storage medium must necessarily be considered. As stated above, the three storage media which appear to offer most promise are the Ferrotron, the Folatron, and double-activated phosphors. Methods of accomplishing the exposure, readout and erasure operations using these three storage materials are discussed below in representative systems.

In the systems described, the storage medium could be interrogated with a spot of light which moves in either a raster scan or in a line scan. While a line scan is simpler to generate, the storage medium must be moved relative to the line. Because of the large numbers of dissected image elements, the raster scan method would require the use of matrix techniques.

In the line scanning method the storage medium could be moved in several ways. For example, after exposure, the medium could be slowly moved past the line scanner into a separate erasure compartment (See Figure 1). After complete readout, it would be rapidly returned to its initial position for re-exposure. Another method involves forming the storage medium into a closed loop (See Figure 2). This would eliminate the rapid return operation, but would require a flexible storage medium. In the following discussion on the application of these promising storage methods, only representative scan methods are assumed.

1. Ferrotron Method

A representative Ferrotron image storage and retrieval system utilizing a combined optical-electrical readout is shown in

LINE SCAN READ OUT USING AN IMAGE STORAGE PLATE

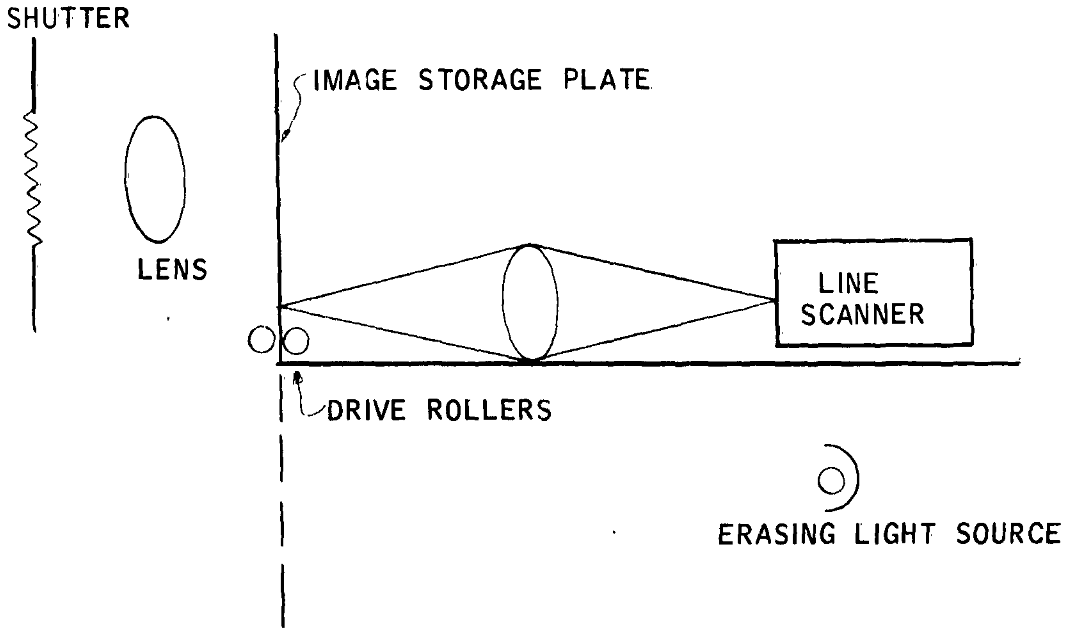

FIGURE 1

LINE SCAN READ OUT USING AN IMAGE STORAGE LOOP

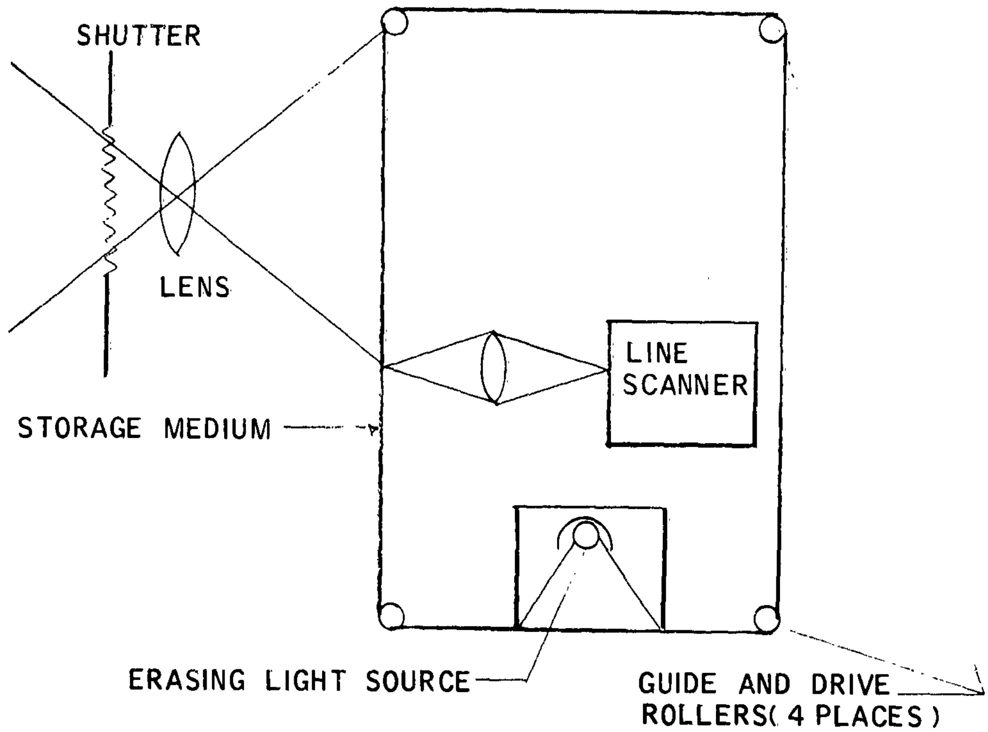

FIGURE 2

Figure 3. Image storage is obtained by closing the "exposure Switch". This applies a voltage pulse across the photoconductor and ferroelectric layers, opens the shutter, and illuminates the electroluminescent grid which decreases the resistance of photoconductor (2). The incident light from the scene decreases the resistance of the photoconductor (1) at each point in correspondence with the scene's radiation. In this way the ferroelectric layer is polarized in a pattern corresponding to the input optical image. Readout is performed by applying a voltage of opposite polarity across each element of the storage medium and integrating the resultant current flow. This integrated value is a measure of the degree of polarization of the ferroelectric and thus the input radiation at any given point. The selection and interrogation of all points of the storage layer is accomplished by moving a light line in incremental (Δy) steps, at each step applying a readout voltage sequentially to all of the conductors of the electrode grid (X). The light bar would be generated by energizing a line of the electroluminescent grid by applying voltages to the electrode grid (Y).The light bar decreases the resistance of photoconductor (2) along its length permitting the voltage from grid (X) to be applied to the ferroelectric at the point of coincidence of the light bar (Y) and the commutated wire in grid (X). The circuit is completed by decreasing the resistance of photo-conductor (1) by illuminating it with a readout flood light.

As stated on Page 93 of the Second Quarterly Progress Report, readout from a Ferrotron image storage plate can be accomplished optically, electrically or by a combined electrical-optical arrangement. For optical readout, a voltage is continuously applied across the ferroelectric layer and a pin-point beam of light scans the stored image line by line. The readout speed of this method, however, is dependent upon the speed of the photoconductive layer which is relatively slow.

FERROTRON IMAGE STORAGE AND RETRIEVAL SYSTEM

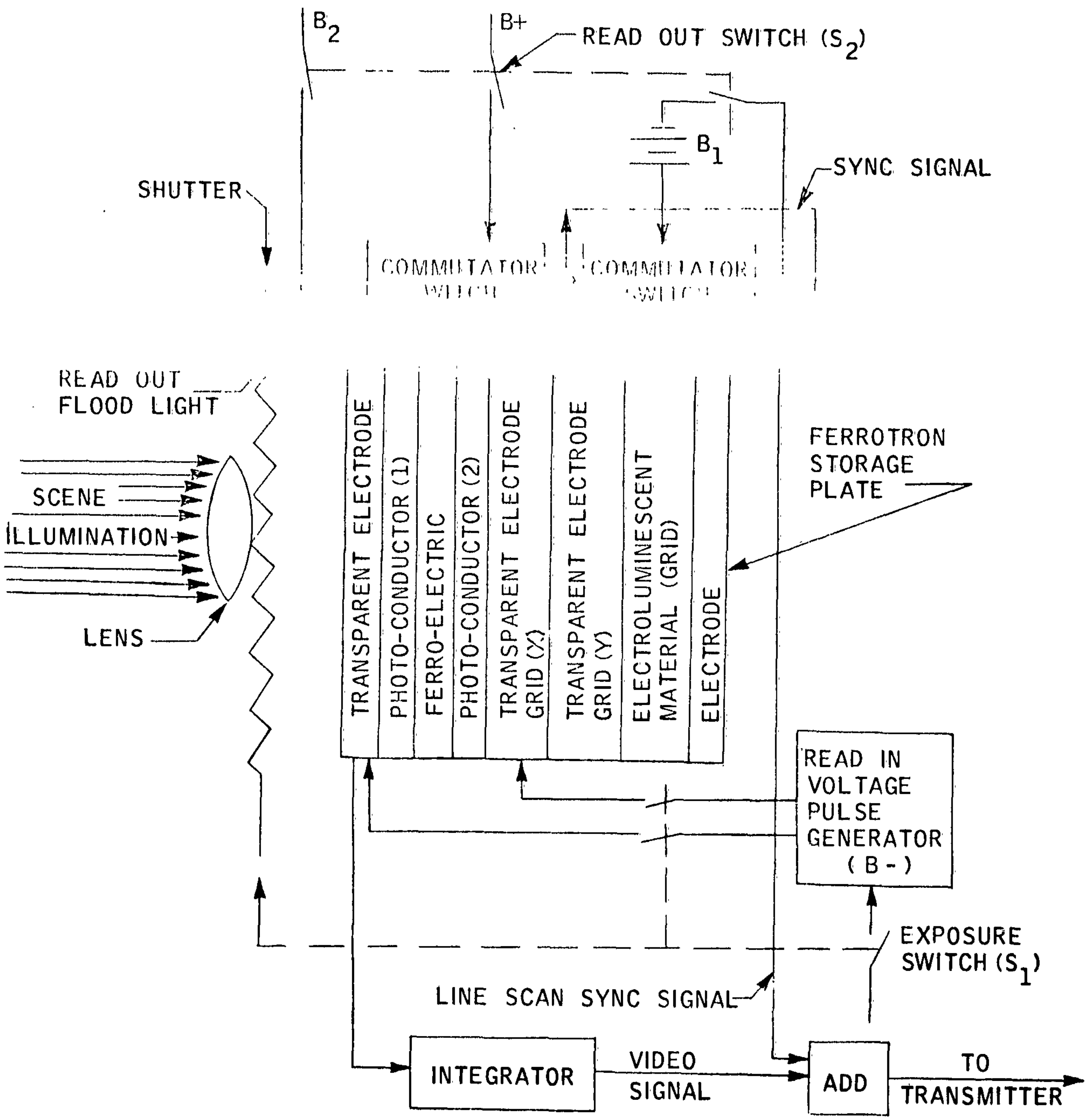

FIGURE 3

Electrical readout could be accomplished by sequential sampling of a matrix grid of conductors placed on both sides of the ferroelectric layer. This method, however, introduces electronic problems due to the high conductor stray capacity. In view of this, a readout technique employing a line of light together with electrical line commutation appears to be the most suitable readout method for this application.

If the Ferrotron storage plate is moved during readout, the light bar can be applied to its front face, greatly simplifying the storage plate (See Figure 4). After exposing the storage plate and polarizing the ferroelectric in the readin operation, the plate is moved past the "readout light bar" for readout. As explained above, this decreases the resistance of the photoconductor along its length permitting point-by-point interrogation of the ferroelectric layer by sampling the electrode grids. After readout, the storage plate is rapidly returned to its initial position in preparation for another readin operation. If a flexible Ferrotron storage medium could be made, a closed loop system such as shown in Figure 2 could be used to eliminate the rapid return operation.

2. Polatron Method

A storage and retrieval system using a PIP memory medium is shown in Figure 5. This storage medium is exposed by irradiating it with light energy from the scene while applying a DC polarizing voltage across it. Readout is accomplished by scanning the memory with a spot of light. Complete erasure after readout is assured by flooding the medium with light from the erasing light source.

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FERROTRON SYSTEM- STORAGE PLATE MOVED DURING READ OUT

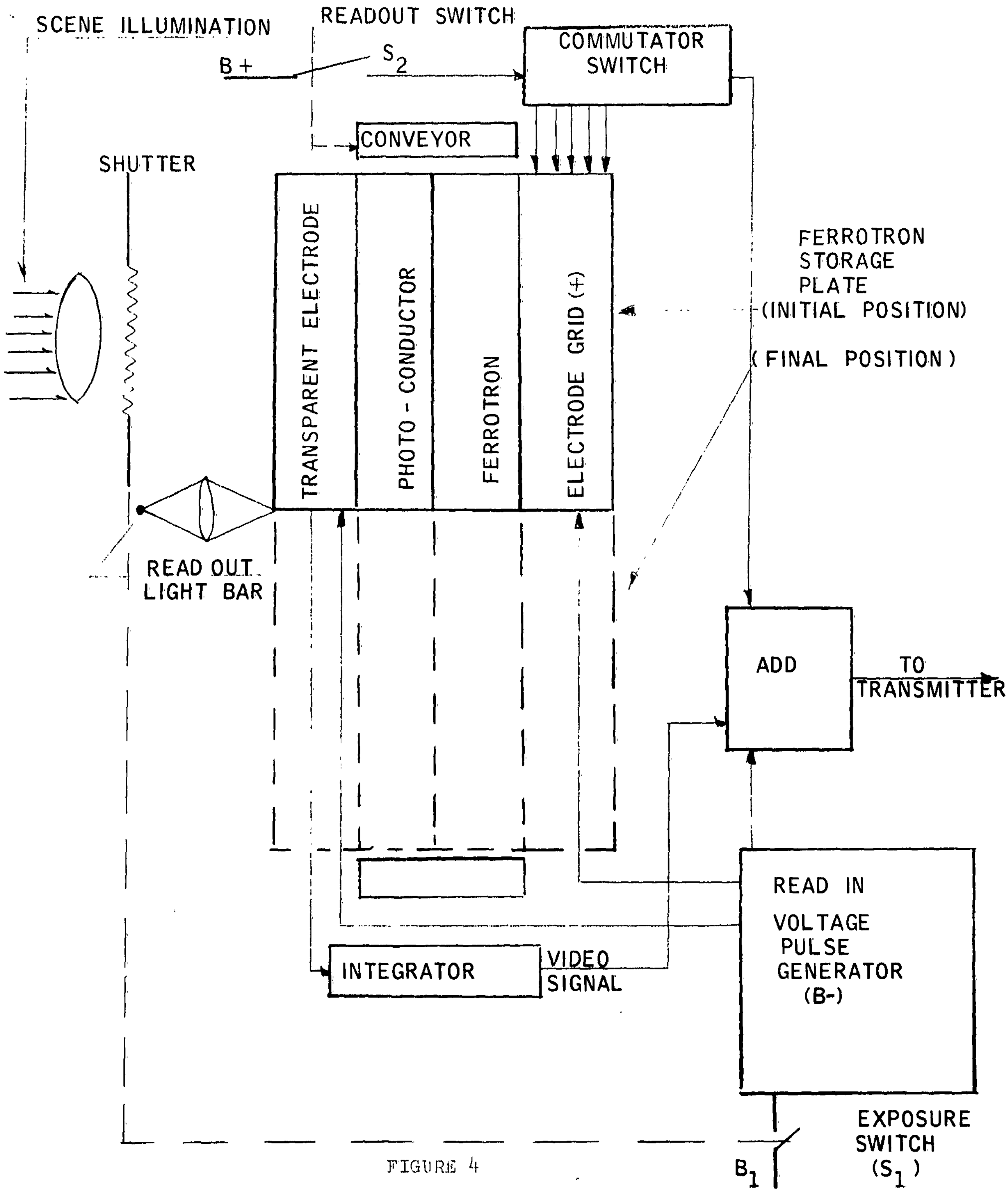

FIGURE 4

P. I. P. IMAGE STORAGE AND RETRIEVAL SYSTEM

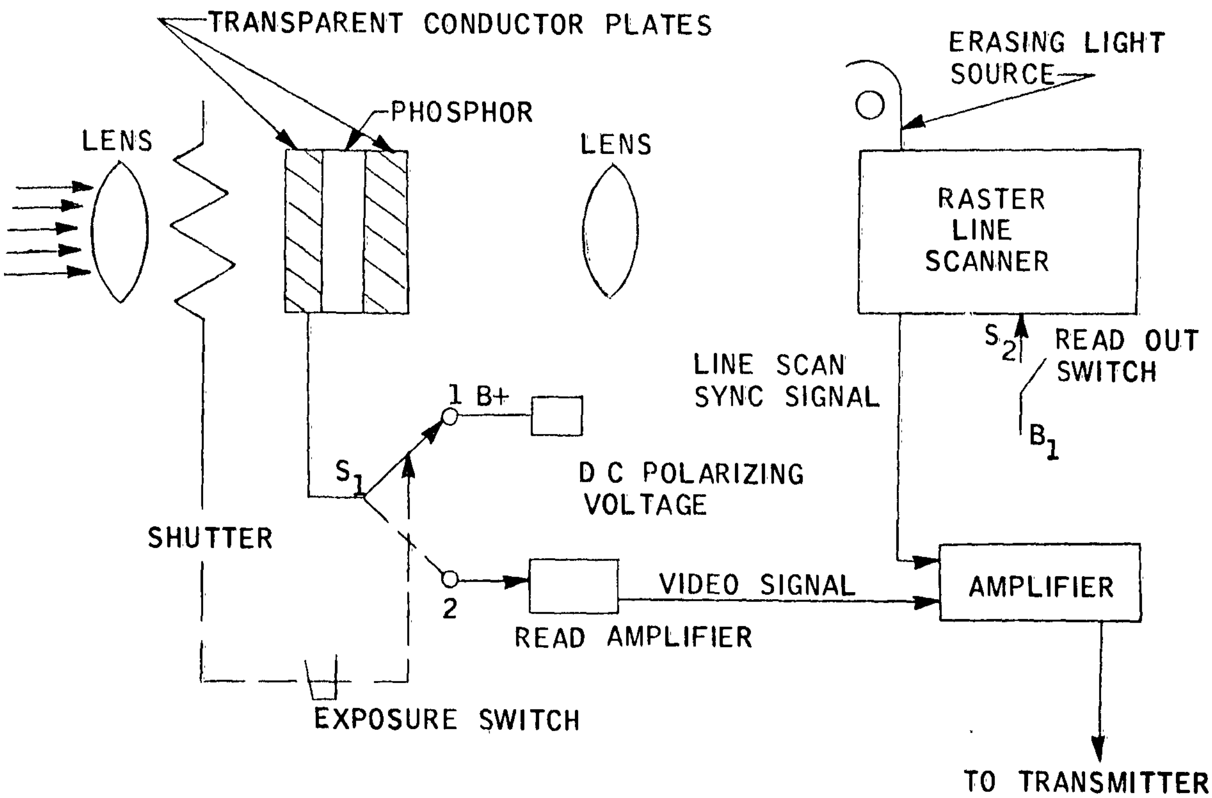

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FIGURE 5

As shown in Figure 5, pressing the "exposure switch" (S_1) applies a DC polarizing voltage across the storage medium and momentarily opens the shutter allowing light from the scene to irradiate the storage plate. After exposure, S_1 returns to position 2 in preparation for the readout operation. Readout is initiated by closing the readout switch S_2. This closure energizes the raster line scanner which scans the memory with a spot of light, extracting the stored image information. The image signals and the scan sync signals are combined and sent to the transmitter for transmission. To ensure complete erasure the storage medium is automatically irradiated by the "Erasing Light Source", preparing the storage plate for another cycle of operation.

3. Double Activated Phosphor Method

A system utilizing a double activated phosphor is shown in Figure 6. Exposure is accomplished by actuating switch S_1 which opens the shutter for the proper time interval. Closure of switch S_2 initiates the raster line scanner which scans the exposed phosphor with an infrared spot of light. The resultant visible radiation emitted from the phosphor is directed to a light sensor by a dichroic mirror and collecting lens. A visible filter is placed in the light path to allow only signal radiation to reach the light sensor. To ensure complete erasure after completing the scanning operation, the storage plate is momentarily flooded with IR from the "Erasing Light Source" after completion of the scanning operation.

PHOSPHOR IMAGE STORAGE AND RETRIEVAL SYSTEM

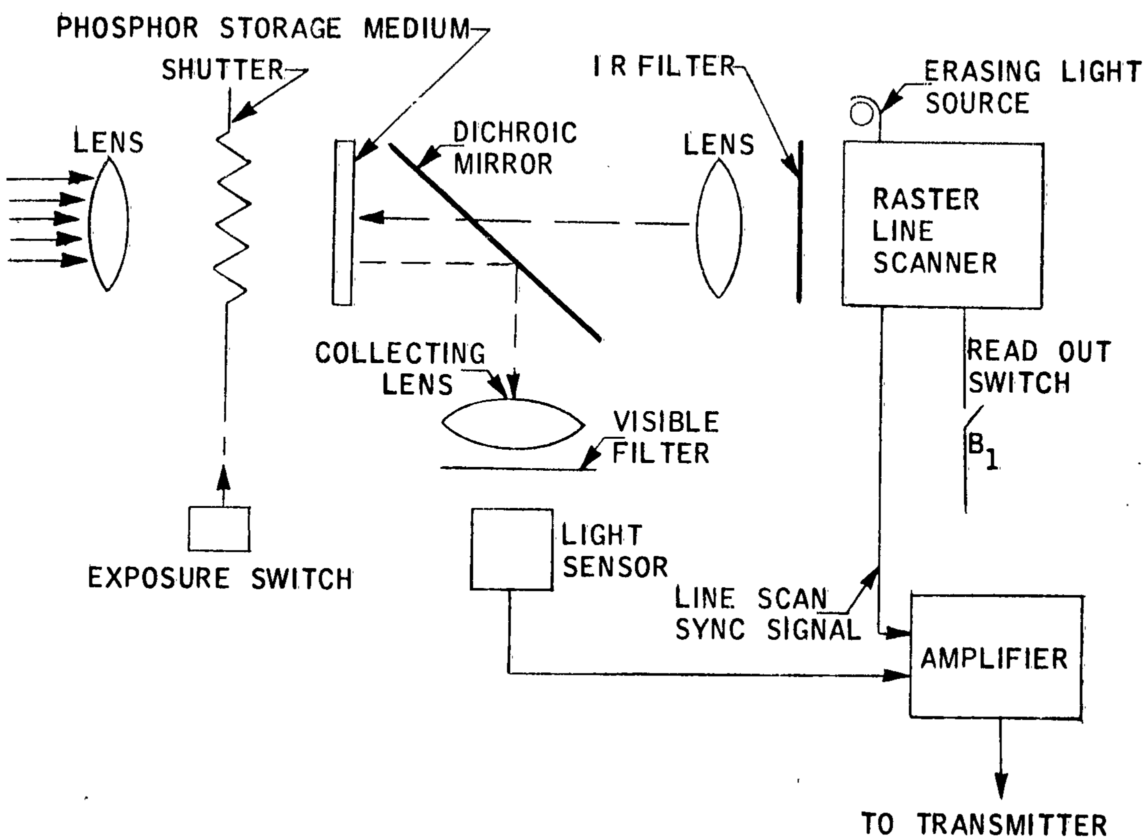

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FIGURE 6

C. RECOMMENDATIONS

The systems analysis work during this period has been concerned with evolving representative image storage and retrieval cycles utilizing the more promising image retention materials. During the next period, it is planned to perform the following:

1. Complete the image transducer parameter study.
2. Utilize the results of the parameter study together with information on the properties of the three more promising image retention materials and knowledge of the image storage and retrieval cycle to compare the theoretical advantages and disadvantages of all evolved techniques.
3. Prepare a plan for experimental work to be submitted to the Contracting Officer or his representative. This will be used as a basis for selection by mutual agreement with the contractor of the most desirable system for subsequent experimental work.

III. COMPONENT RESEARCH

A. SUMMARY

An investigation was initiated during this quarter to examine the characteristics of a persistent internal polarization device for possible use as an image transducer. A literature search revealed that such a device can provide the desired resolution and readout speed.

Further analytical and experimental investigation of readout methods has been continued during this quarter but this effort was directed specifically to the ferrotron matrix. Since the ultimate image transducer will involve a large number of elements to achieve adequate resolution (4 million or greater) particular emphasis was placed upon realizing an economy in the electronic switching circuitry necessary to scan the matrix. Various circuit implementations were reviewed and compared on the basis of component count. It is shown that an appreciable savings in circuitry (approximately 40%) can be made by using a form of "3-dimensional switching" to gain access to the elements of the matrix.

A review of the properties of a ferroelectric matrix cell indicates that the use of ferrotron elements overcomes certain inherent limitations of such a matrix. The ferrotron element, by using a photoconductor in conjunction with the ferroelectric material, provides an increased isolation within the matrix and a satisfactory thresholding element with external control.

An experimental investigation was conducted to examine the read-in and readout characteristics of a ferrotron element under

varying conditions of spectral bandwidth, frequency, and amplitude of the input flux. These experiments indicated that the ferrotron element operated most efficiently with the input flux restricted to the range from 5500 to 6000 angstroms. Quantitative data from other experiments has not been reduced at this time.

B. POLATRON

The work of Kallmann and Rosenberg suggests the possibility of an image transducer using the persistent internal polarization effect. Experimental data storage and display units have been constructed and tested by Kallmann and Rennert while a photographic process employing persistent internal polarization and dyed charged resin particles was devised by Kallmann et al. The techniques devised in these investigations can be modified for use in an image transducer as the input is a light signal and the output a voltage pulse.

Both excitation and de-excitation of the polarization can be accomplished by exposure to light. Consequently, it is possible to obtain either a positive or negative polarization image in memory. This latent polarization can then be converted to a voltage signal by de-excitation of the specimen with incident radiation.

In the experiments reported above, commercial zinc cadmium sulfide phosphors with average particle diameters of about 10 microns were deposited on electrically conductive glass plates (Nesa glass plate) by sedimentation from solutions of cellulose nitrate in amyl acetate. The supernatant liquid was withdrawn and the remaining solvent driven off by heating (with infrared heat lamp, for example). In this way, uniform layers of about 25 mg/cm^2 were obtained.

The phosphor with the strongest PIP effect reported is referred to as K powder. Spectral analysis of the K powder yields the following composition: 43.7% ZnS, 56.3% CdS, 0.01% Cu, 0.0025% Au; 0.003% Ag, 0.015% Pb, 0.0005% Ni.

Kallmann and Rennert report a device employing the scanning beam of a TV tube as a source of de-excitation radiation for reading out the polarization. The resulting output voltages were used to control the intensity of a monitoring oscilloscope the sweep of which was synchronized to that of the scanning beam of the TV tube. This scheme was also used to read-in information using a pre-excited plate. In their preliminary experiments they achieved writing rates of about 0.1 millisecond per bit of information with a resolution of about 0.1 millimeter. The plate size was one square centimeter.

Subsequent investigations show that measurable signals can be obtained using reading and writing speeds of 0.5 microseconds. Erasure can be accomplished easily within a microsecond by use of a high intensity light flash.

The resolution in the preliminary experiments was undoubtedly limited by the powder particle size, namely 10 microns. To improve the resolution either a finer powder or single crystal slabs could be employed. An order of magnitude increase in resolution should be possible.

C. MATRIX SWITCHING - FERROTRON

A complete analysis of the problems involved in switching large numbers of storage elements must consider (1) the characteristics or storage mechanism of the individual cell and (2) the problems associated with obtaining access to any one particular cell out of a large number of cells. These factors, therefore, must be examined when selecting a method of switching a large ferroelectric matrix.

1. The Storage Element

A ferroelectric is a material which exhibits a spontaneous electric dipole moment (polarization) even in the absence of an applied electric field below a certain critical temperature. The ferroelectric can exist in the depolarized state as the polarization does break up into a domain pattern analogous to the behavior of the magnetization in ferromagnetic materials. Application of an electric field will then result in the specimen being polarized in the direction of the applied field. Removal of the field does not reduce the polarization to zero as the relationship between applied field and polarization is not reversible. Consequently, the polarization does not depend upon the applied electric field alone but rather is determined by the previous electrical history of the specimen as well as the applied electric field.

When used in place of a dielectric in a capacitor, ferroelectrics produce non-linear capacitors of great charge-storing capacity. The effective dielectric constant depends very strongly on the state of polarization relative to the applied electric field.

In fact, the direction of polarization can be determined by application of a voltage sampling pulse. Furthermore, there are two stable directions of polarization thus permitting operation in a bistable mode.

A large number of ferroelectric materials exist and considerable research efforts, both theoretical and experimental, have been devoted to materials such as barium titanate, $BaTiO_3$. The various ferroelectric materials can be obtained in both ceramic and single crystal form. The single crystal form is more desirable since it exhibits a greater degree of polarization for a given applied field.

The Curie temperature of a ferroelectric material is important because it is that temperature above which the material ceases to exhibit spontaneous polarization. This temperature varies for different feroelectric materials; the Curie temperature for barium titanate, for example, is 120°C. Below and close to the Curie temperature the coercivity of the material and the spontaneous polarization vary almost linearly with temperature. In addition to this temperature dependence, the same type of variation is encountered due to internal heating of the material that occurs with increased switching frequency. The hysteresis loop exhibited by a given ferroelectric material changes in rectangularity as the switching frequency is increased.

Another characteristic of all ferroelectric materials is the lack of a definite threshold field necessary to obtain a polarization reversal. An auxiliary form of thresholding ordinarily must be employed in all applications in which a large number of ferroelectric elements is used. For selection of one element from a large number of elements at least two methods can be used: the selection may be made externally, or some nonlinear element such as a diode may be used in conjunction with each ferroelectric element to provide the proper thresholding.

In switching the polarization of ferroelectric materials it is desirable to use a voltage pulse with a rise time considerably shorter than the pulse duration, T_s. For a given ferroelectric material, the inverse of the switching time, T_s, is proportional to the applied field strength. T_s is also proportional to the thickness of the element.

As discussed in Quarterly Report II the Ferrotron represents a desirable matrix element for use in an image transducer. The ferrotron consists of a ferroelectric element sandwiched with a photoconductive element. Read-in is provided by light incident upon the photoconductor causing the ferroelectric to change polarization.

The use of the photoconductive element in conjunction with the ferroelectric element accomplishes two purposes: (1) a very satisfactory thresholding element with external control is provided (2) an increased isolation within the matrix is achieved which tremendously increases the overall signal to noise ratio.

In addition, the use of a bar of light to scan the rows of a matrix for readout can reduce the matrix wiring complexity. Again, an external control or switching by this optical scan can provide for greater flexibility in the use of the matrix.

2. Scanning Methods

Some of the normal methods of electrically scanning a ferroelectric cell configuration (without the photoconducting layer of the ferrotron) to recall information in a non-random scanning pattern are:

(1) linear scanning
(2) square or rectangular matrix scanning

For linear scanning, ferroelectric elements may be arranged in a single line. In this trivial case the read pulses may be switched sequentially from element to element. The opposite electrodes of all elements may be connected in parallel to a common resistance. By sensing the change in current through the resistance, the readout is obtained. This type of scanning must be restricted to small matrix configurations because of the amount of scanning circuitry per bit of information.

The ferroelectric elements may be arranged in a square or rectangular matrix to realize a savings in circuitry. (One switch selects a complete line of elements instead of only one element as above. If the number of switches is divided by the number of elements the savings is evident.) On one side of the matrix, conductors may be deposited on each row of elements. On the other side of the matrix conductors may be deposited for each column of elements. In the simplest form of scanning, voltages of amplitude +V and -V with regard to ground are applied to the desired row conductor and column conductor. The magnitude of the voltage V must be chosen such that 2V is sufficient voltage to reverse the polarization. For this condition a voltage, V, will be applied to all elements except the desired element. This element will have an applied voltage of magnitude 2V. Thus what is referred to as a 2 to 1 selection ratio can be obtained.

A three to one selection ratio will further reduce the signal to noise ratio. This ratio may be obtained by applying a back voltage of V/3 to the unselected conductors above.

As mentioned above, a readout can be obtained in a simple manner when scanning a ferroelectric matrix by sensing the change in current through a resistance. However, two basic problems must be considered. The first factor is the discrimination necessary to distinguish between the readout of degrees of polarization, ranging from negative to positive saturation due to applied voltage which produces a change in current in the readout circuit. If the element is in the negative state and the voltage is applied, a small change in polarization is still experienced due to the lack of complete squareness of the hysteresis loop and a small current is drawn from the source. The voltage produced by the current change in this latter case must be minimized. A number of approaches to this problem have been employed: (1) diode clipping across the load resistance (2) integration with a capacitive resistive load (3) the use of judicious time sampling and (4) frequency sampling.

The second basic problem in the ferroelectric matrix is concerned with the undesired voltages that appear across unselected matrix junctions during matrix selection. These voltages are known as "half select" voltages and produce an undesired change in polarization. This change represents an undesired loss in effective "charge" and hence a gradual loss of memory.

The basic logical arrangement most commonly used for scanning is shown in Figure 7. Both the column and row scanners exhibit the characteristics of sequential commutators. The column scanner, for example, will provide an output on the next column position each time a pulse is applied to the input of the scanner. In this way each column in the matrix is successively selected. When the last column for a given row has been scanned, the column scanner will provide a pulse on the output line. After a delay, this pulse will be applied to the input of the row scanner. The row scanner switches to the succeeding row and the cycle is repeated.

The scanning functions can be implemented by electronic circuitry or by electromechanical commutation. Selection might be made on the basis of necessary commutation speed, desired operating life, the amount of noise that may be tolerated, or the amplitude of voltage or current that must be switched. These parameters must be specified in the environment of the specific application.

Straightforward electronic scanning can be accomplished by:

(1) a solid state counter with a diode matrix output
(2) a magnetic commutation switch with drivers
(3) a series of solid state shift registers
(4) a series of tapped delay lines

The solid state counter is designed to provide a count equal to the number of matrix lines that must be switched. The diode matrix is necessary to provide for the selection of consecutive matrix lines in accordance with the count in the counter. In essence, the

THE BASIC LOGICAL ARRANGEMENT FOR SCANNING

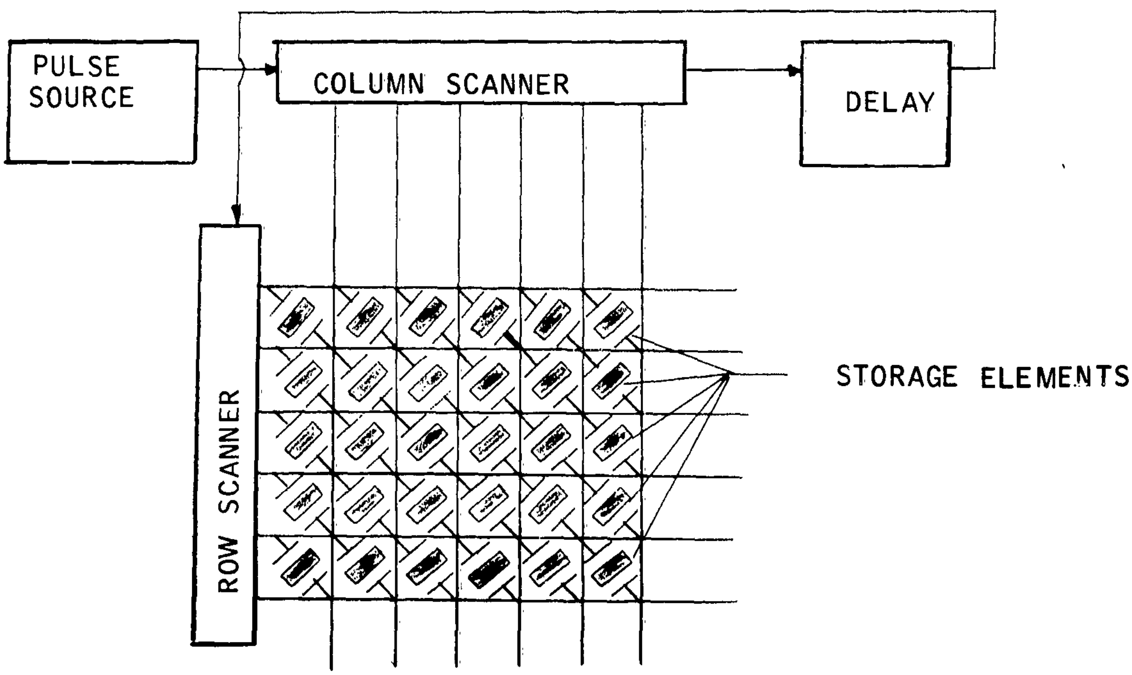


FIGURE 7

matrix consists of a number of gating circuits with each gating circuit used to energize a given matrix line. A given gating circuit in turn will be activated by a given count in the counter. If the number of elements in a matrix line is quite large, a separate drive amplifier must be provided for each line to furnish sufficient drive.

A magnetic commutation switch consists of a linear configuration of ferrite cores. The cores are wired in series such that each incoming pulse switches the next core in the linear array. Since the lines of the matrix are connected to the individual cores by drive amplifiers, successive lines are sequentially energized. For large matrices, the commutation switch is segmented into smaller commutation switches and regenerative amplifiers are provided between each section.

Another matrix scanning arrangement can be implemented by a solid state shift register. Such a shift register is composed of a series of transistor switches. The stages of the register are sequentially energized by the incoming pulses. The individual lines of the matrix are connected directly to the individual matrix lines.

Scanning can be provided by use of tapped delay lines. The individual taps on the delay line are connected through drive amplifiers to the matrix lines. A given pulse fed into the delay line will thus appear at successive taps. Due to pulse degeneration in a delay line, the length of the line must be limited. Hence, for large matrices, a number of delay lines must be used.

In the above discussion, an indication was made of the savings in switching circuitry that may be realized by use of two-dimensional matrix switching rather than a single line scanner. This principle can be further extended with an additional reduction in circuitry. For example, three-dimensional matrix switching can be provided by dividing the arra of elements into discrete areas, or planes. In addition to row and column switching, circuitry is provided to select planes within the total array.

A simplified switching schematic is shown in Figure 8. The switches are designated as "X", "Y", and "Z" switches. In a typical switching operation, the first element would be selected by closing both the X, and Y, switches, and the Z_1 switch to select plane #1. Next, the X_1, Y_2, and Z_1 switches would select the second element. This switching pattern would continue until all of the elements along the X_1 line had been selected in plane #1. Then the switch Z_2 would be closed and with appropriate X and Y switching the elements on line X_1 of the plane #2 would be selected. This pattern will continue until all of the elements within the planes and all of the planes of the matrix have been scanned.

Use of this method of switching may be both technically and economically advantageous for switching large numbers of elements that require voltage switching. A penalty is incurred by the capacitive loading that is always present when driving many elements in parallel. This penalty must be paid for by a decrease in switching time. A certain degree of complexity is added to the wiring because of the segmented areas. These ramifications must be examined in detail.

In line with the minimum image transducer requirements a matrix of at least 2000 by 2000 elements provides an estimate of minimum size. For this requirement a scanning switch with at least

SIMPLIFIED SWITCHING ARRANGEMENT

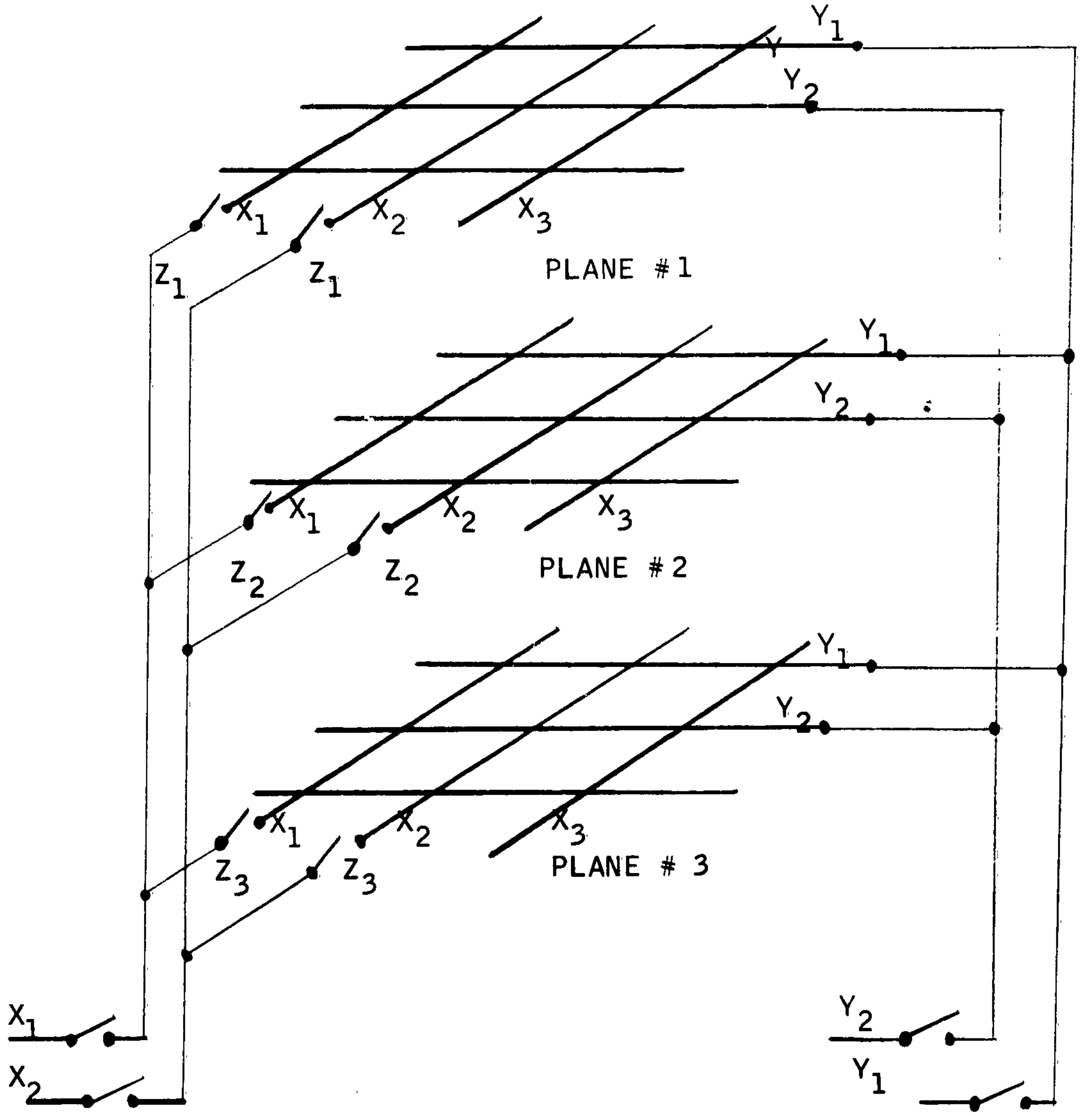


FIGURE 8

2000 outputs is desired. For a switch of this magnitude the choise of implementation must necessarily be influenced strongly by fabrication cost and component count. Table 1 shows relative component count of these arrangements.

In the ferrotron matrix readout a form of three-dimensional switching may be provided by using a light beam in conjunction with conventional electronic column scanning. In this case the individual planes and the columns are selected by electronic switching. (See Figure 9). Row selection is made with a light beam incident upon the photoconductor elements of a given row. The electronic switching will place the voltage required to switch the ferroelectric cell across the selected ferrotron element. Until the light beam excites the photoconductive wafer of the element, by voltage division, most of the voltage appears across the high resistance of the photoconductor. The impinging light causes the photoconductive resistance to decrease to a low value, and the major portion of the voltage then appears across the relatively higher resistance of the ferroelectric cell causing it to read out.

An example can be provided by considering a matrix consisting of four million ferrotron elements. This matrix can be divided into 160 planes or segmented areas. Each plane would consist of 160 rows and 160 columns of ferrotron elements. An advantage is realized by driving the columns of all planes in parallel from the same 160 switches. An additional 160 switches provide for the plane selection.

One method of generating the light beam described above can be provided by using electroluminescent panels. See Figure 10.

TABLE I

RELATIVE COMPONENT COUNT OF
VARIOUS METHODS OF ELECTRONIC SCANNING

	Approximate No. of Transistors	Approximate No. of Cores	Approximate No. of Diodes	Approximate No. of Delay Lines
Counter with Diode Matrix	60	--	18,000	--
Magnetic Commutation	4000	4000	400	--
Shift Registers	4000	--	400	--
Tapped Delay Lines	4000	--	--	1000
3 Dimensional Switching	144	--	2400	--

FERROTRON MATRIX SWITCHING

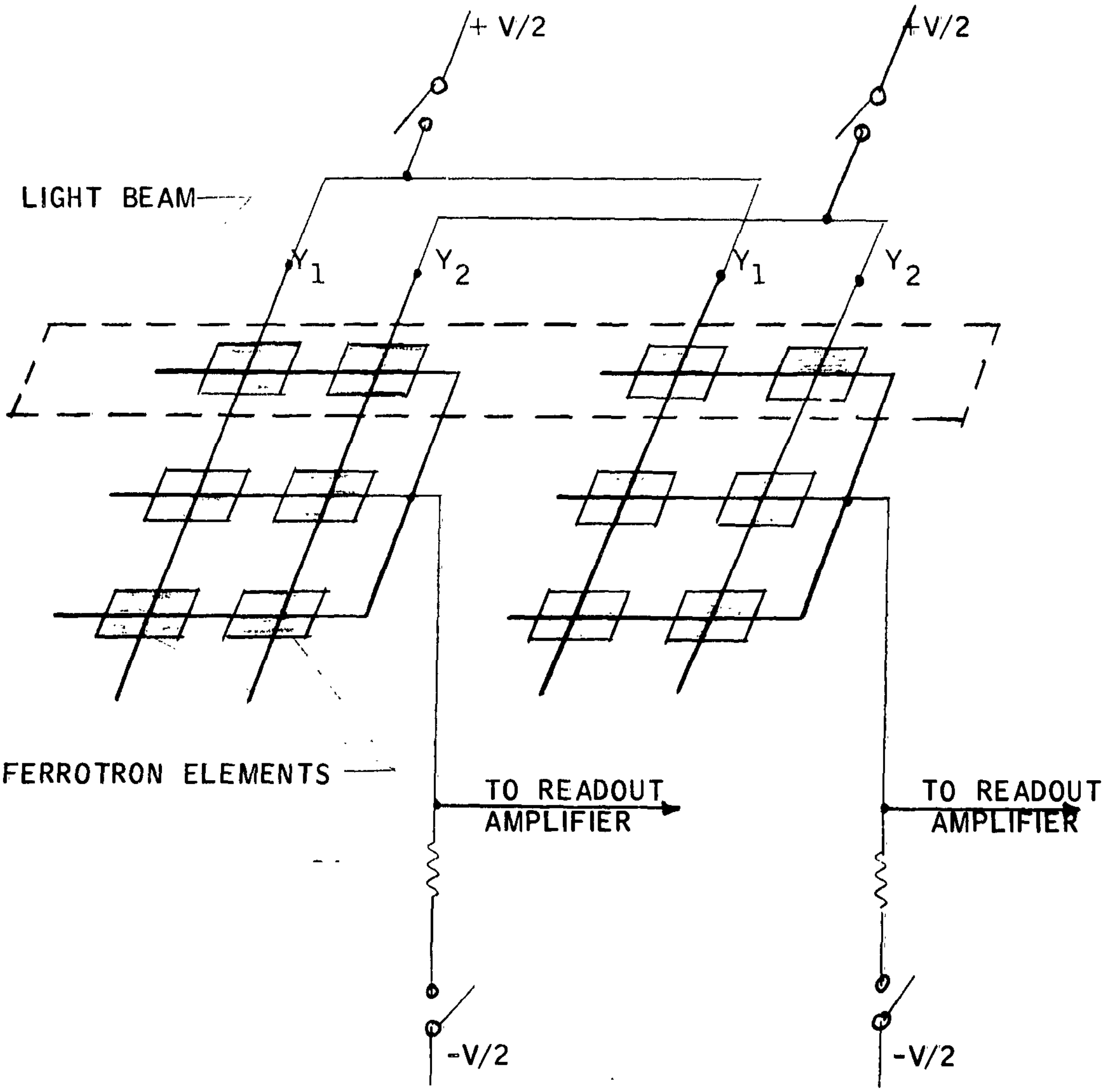


FIGURE 9

LIGHT BAR GENERATOR

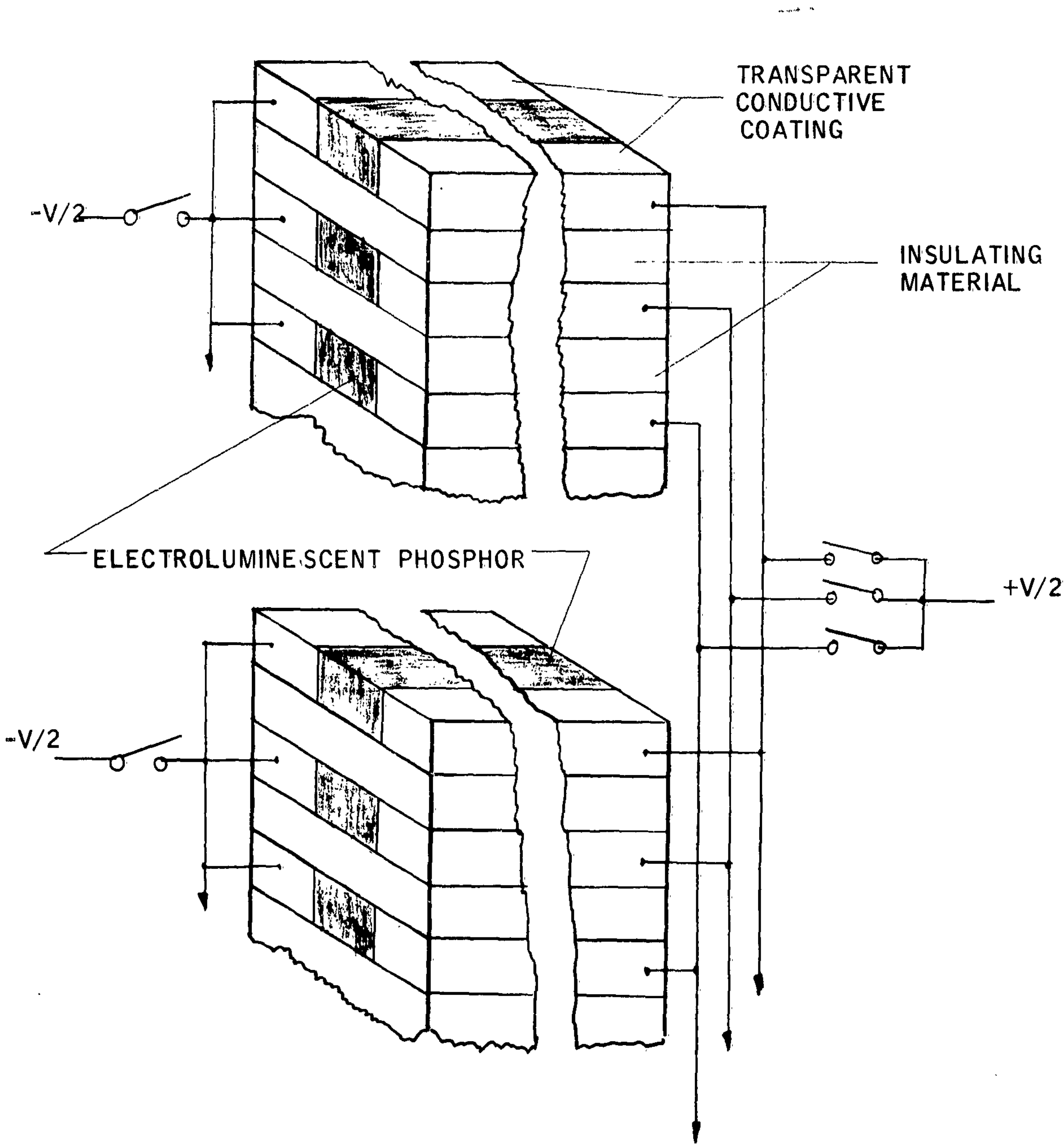


FIGURE 10

The elements are bar-shaped and sufficiently long to provide light for an entire row of the ferrotron matrix. A reduction in switching circuitry might be realized, for example, by using 160 panels. Each panel would provide 160 bar elements. An individual panel is selected by applying half of the exciting voltage to all of the bar elements on one side of the panel. The individual element within a panel is selected by applying the other half of the necessary exciting voltage to that particular element. The voltage for bar selection might be applied to all panels in parallel.

D. EXPERIMENTAL INVESTIGATION OF FERROTRON

1. Description of Test Set-up

The apparatus employed for investigating the characteristics of the Ferrotron for application in an image transducer consists of the following:

a) A monochromator and stable light source
b) A chopping disk driven by a variable speed motor
c) A photoconductive switch and reference light source
d) A cathode ray oscilloscope
e) A battery potential source for the Ferrotron and photoconductive switch

The test set-up is depicted in Figurell, a block diagram in Figure 12.

The monochromator (Bausch and Lomb Serial HD 6608) contains a wavelength selection drum and an exit slit for setting spectral bandwidth. Turning the wavelength drum rotates a grating in order that the desired portion of the spectrum is transmitted by the monochromator. The circular chopping disk has two slots whose centers are located on a common radius but at different radial distances from the center of the disk. The disk is driven by a Bodine electric motor, model NSH 12R; a speed control permits selection of the chopping frequency.

Luminous flux from the monochromator is directed by means of a prism onto the chopping disk at the same radial distance as the read-in slot and the Ferrotron. The reference light and the photoconductive

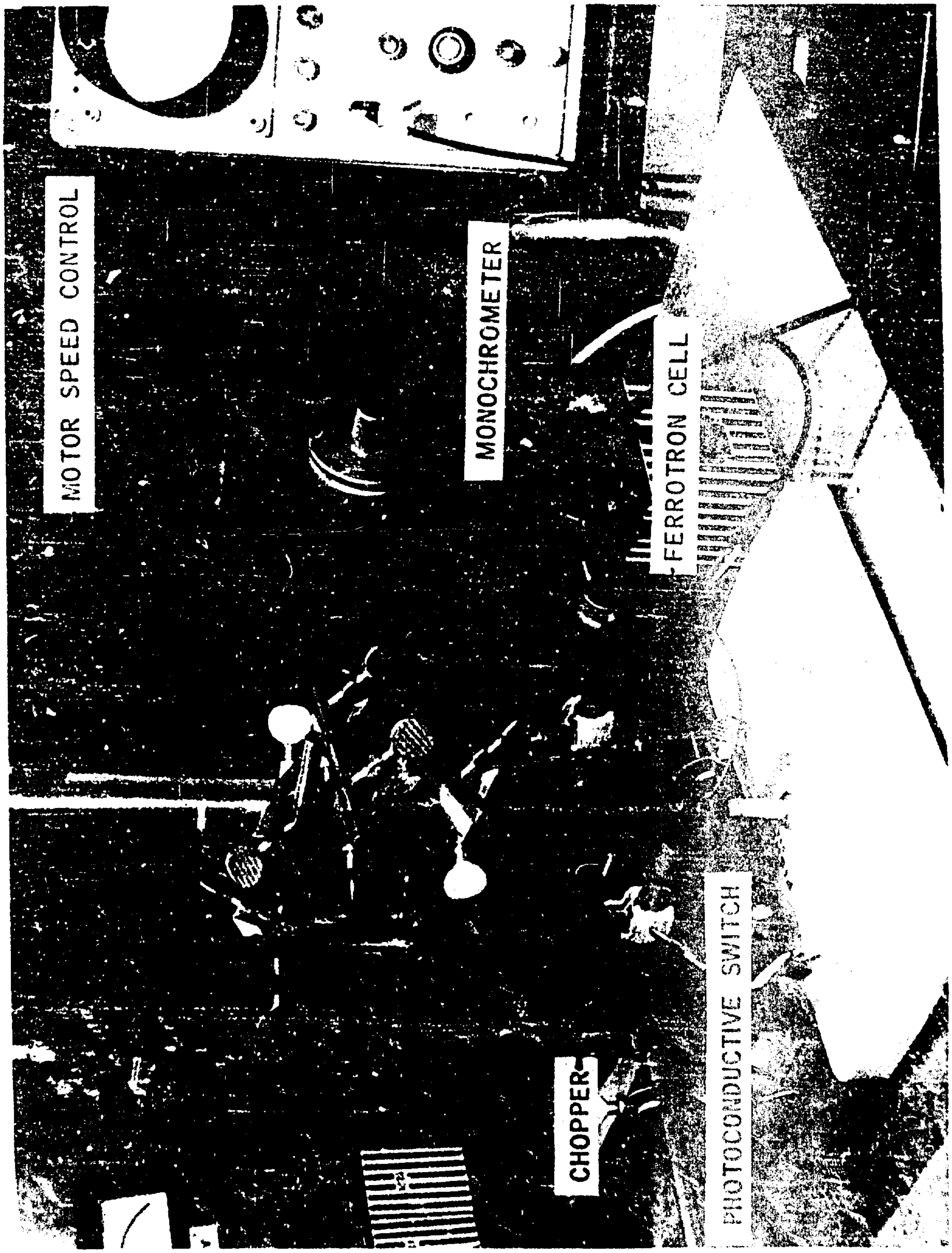
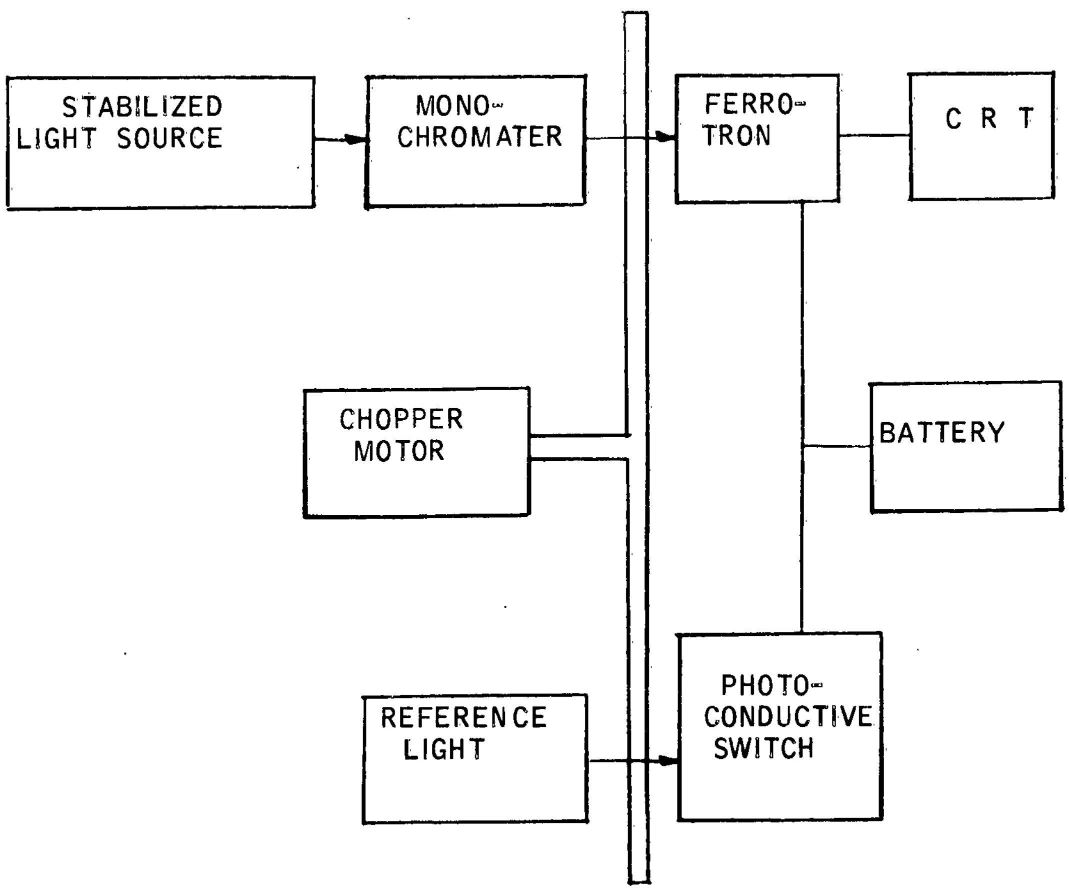

MOTOR SPEED CONTROL
MONOCHROMETER
FERROTRON CELL
CHOPPER
PHOTOCONDUCTIVE SWITCH

FIGURE 1[illegible]

BLOCK DIAGRAM OF TEST SET UP



(ARROWS DENOTE LIGHT PATH)

FIGURE 12

switch are positioned diametrically opposite the read-in light and Ferrotron, at the same radial distance as the readout slot. Therefore, at a disk rotation of approximately 140 degrees after the point where the read-in slot terminates, obscuring the Ferrotron, the read-in slot admits light from the reference light to the photoconductive switch. A further rotation of the disk of approximately 140 degrees beyond the point where the photoconductive switch is obscured results in illumination of the Ferrotron, and the cycle is completed.

The output of the Ferrotron is connected to a 500,000 ohm load resistor (see Figure 13). When the Ferrotron is triggered by the photoconductive switch during readout, the current pulse it delivers through the load resistor generates a voltage pulse across the resistor. A cathode ray oscilloscope (a Tektronix 535A) is used to observe the voltage output during both the read-in and the readout. It may be seen by referring to Figure 13 that the photoconductive cell and the Ferrotron are connected in series with potential sources but of opposite polarity. Hence, the read-in pulse is negative-going, while the readout pulse is positive-going.

2. Experimental Procedure

The flux entering the monochromator is determined by the width and height of the entrance slit. Once each revolution of the disk, the flux passes through the read-in slot and impinges upon the Ferrotron; the amount of flux (i.e. the exposure) is a function of the size of the read-in slot and of the rotational speed of the chopper. The rotational speed also determines the frequency with which the Ferrotron is illuminated. Since it is possible to vary the width and height of the entrance slit, the speed of the chopper motor, and the size of the read-in slot (by masking), a wide range in illumination level of the Ferrotron in any spectral region may be achieved.

CURCUIT DIAGRAM OF EXPERIMENT

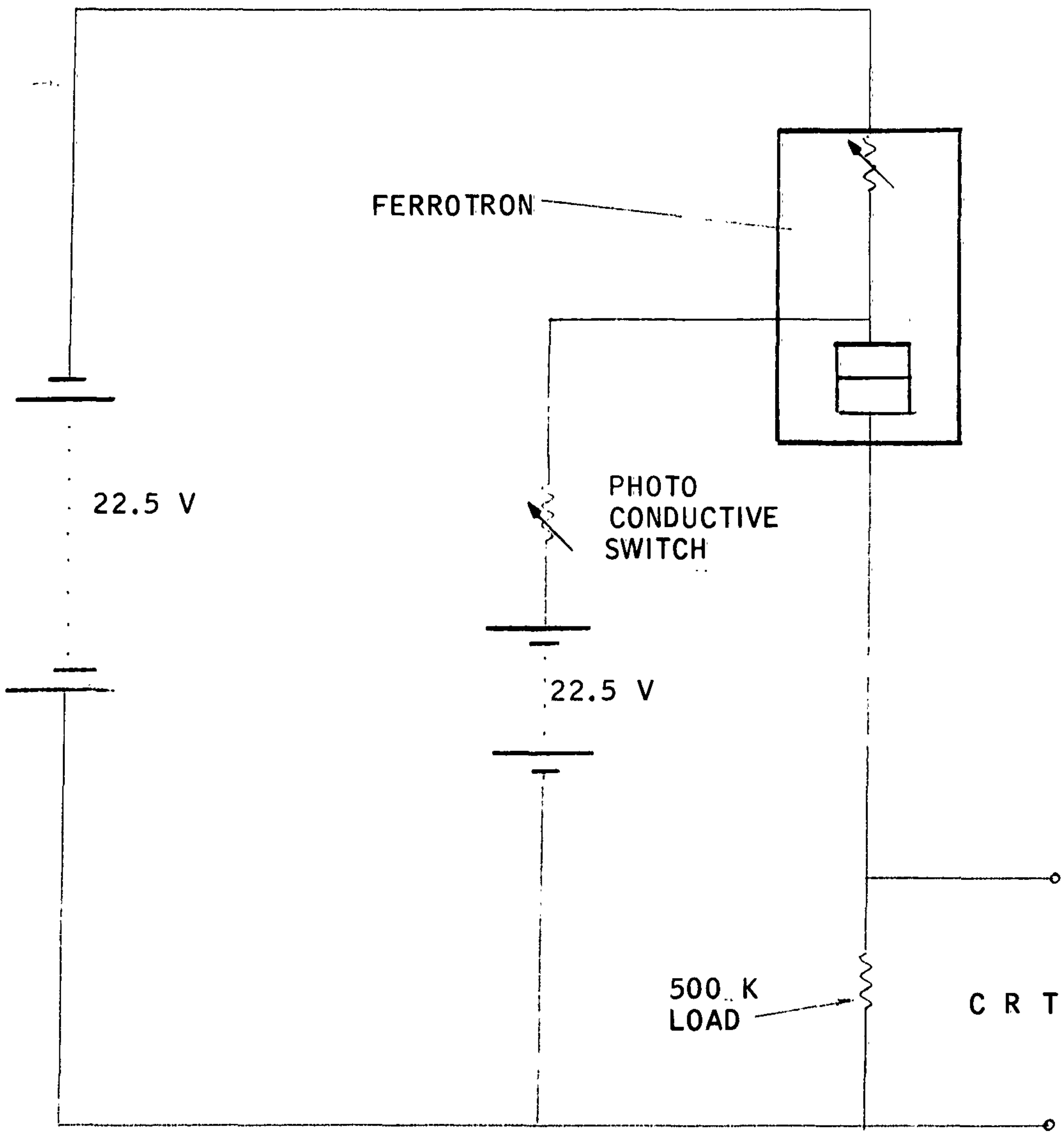


FIGURE 13

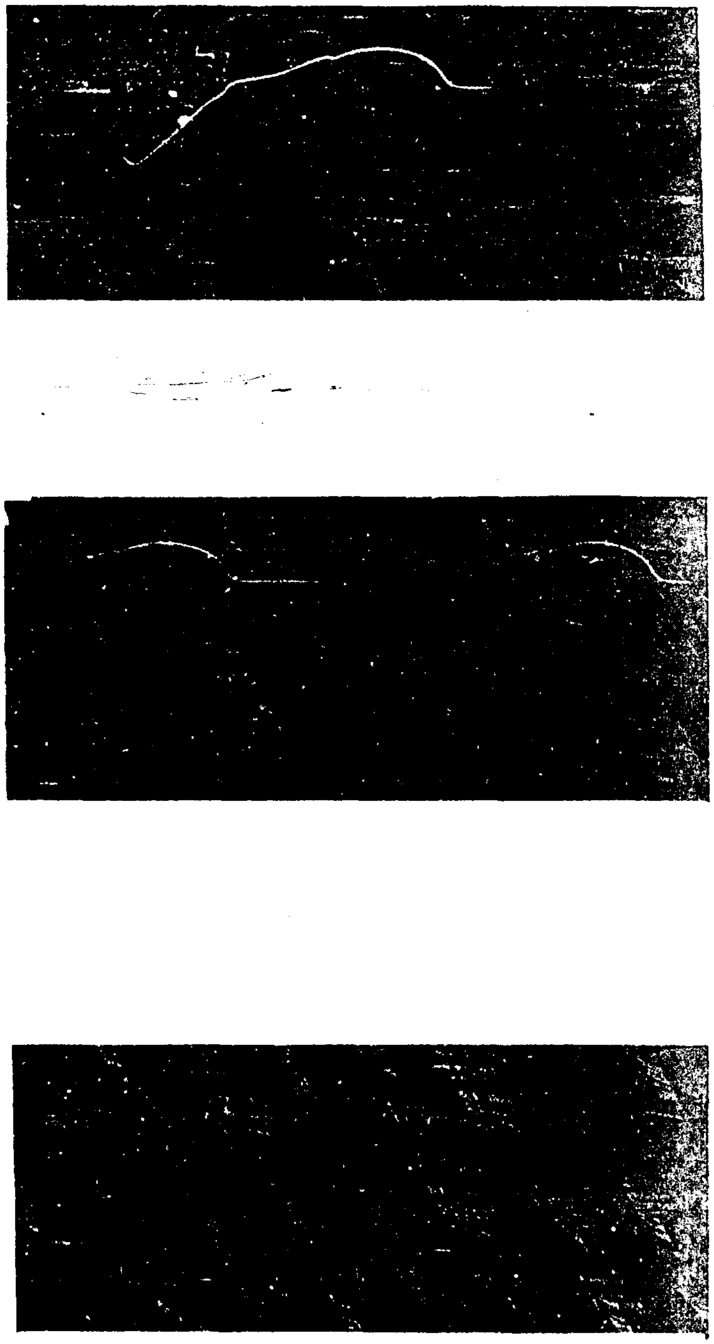
Since the only function of the photoconductive switch is to provide a triggering signal to permit readout of the stored signal in the Ferrotron, it is necessary only to provide sufficient illumination to assure that photoconduction takes place whenever the chopper disk has rotated to the point where the readout slot will permit flux from the reference light to impinge upon the switch.

3. Test Results

In Figure 14 is shown the effect of varying the read-in illumination level by varying the width of the entrance slit. For the three photographs comprising Figure 14, the exit slit was set at 1.68 mm and the drum at 5600 Angstroms; the oscilloscope sweep rate was set to require 10 milliseconds per cm and the vertical sensitivity was 10 volts per cm. The chopper motor speed control was set to give a stationary scope presentation. The slits were set at their maximum heights. The entrance slit width was set to admit a particular flux in Figure 14 (a), 40% as much flux in Figure 14 (b), and 20% as much flux in Figure 14 (c). There is only a small change in amplitude between Figure 14 (a) and 14 (b). In Figure 14 (c), a marked change in amplitude and pulse shape has occurred. In addition, the interval between adjacent read-in and readout pulses has decreased.

In Figure 15 an entrance slit width of 4 mm was established and the effect of varying the wavelength is presented. For Figure 15 (a), the wavelength setting was 5000A°; for Figure 15 (b), it was 5500°A, and for Figure 15 (c) it was 6000A°. It is seen

FERROTRON SCOPE PATTERNS
VARIATION OF ENTRANCE SLIT-WIDTH



A

B

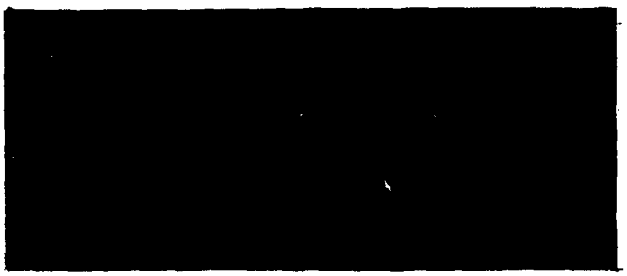
C

FIGURE 14

FERROTRON SCOPE PATTERNS
VARIATION OF WAVELENGTH

A

B



C

FIGURE 15

that little change in amplitude and expulse shape took place between 5000A° and 5500A°, while a considerable change occurred in going from 5500A° to 6000A°, where the pulses are of larger amplitude.

In Figure 16, the effect of varying the width of the exit slit is observed for an entrance slit of 4 mm at a wavelength of 5600A°. The various settings used are presented in the table below:

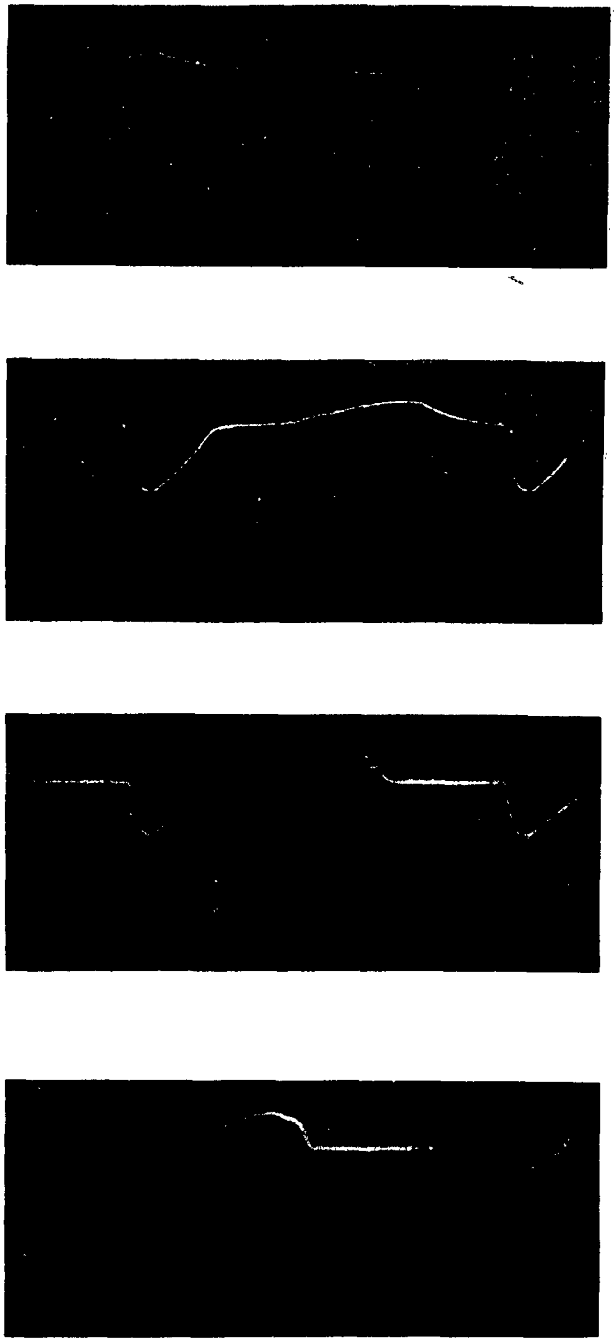
Figure	16 (a)	16 (b)	16 (c)	16 (d)
Exit Slit Width	0.5mm	1.0mm	1.5mm	2.0mm

It is interesting to note the similarities which exist between Figures 14, 15 and 16. As more energy impinged upon the ferrotron, the pulses naturally become larger. With sufficiently large pulses, the narrow section of disk bisecting the read-in slot is apparent,(Figures 14 (a), 14 (b), 15 (c)). It appears to be evident in 16 (b) and (c) also, but in 16 (d) the read-in pulse has been peaked before the slot has rotated to its midpoint and the bisecting section no longer interferes with the pulse rise characteristic.

While the foregoing experiments were carried out primarily to establish the efficacy of the test setup in controlling the many variable parameters which influence a critical evaluation of the ferrotron elements, some general conclusions concerning its applicability to an image transducer may nevertheless be made:

(a) read-in is accomplished in less than 20 milliseconds
(b) readout requires the same order of time
(c) image retention of over one minute is possible
(d) complete erasure occurs during readout

FERROTRON SCOPE PATTERNS
VARIATION OF EXIT SLIT WIDTH



A

B

C

D

FIGURE 16

E. RECOMMENDATIONS

During the next report period the following tasks should be performed.

(1) The investigation of the various aspects of matrix switching for readout should be continued. This examination should relate specifically to the ferrotron and the polatron. In addition to component count comparisons, the factors related to switching speeds should be emphasized.

(2) The study of the compatibility of various components that may be used in combination to form an image transducing system should be continued. Figures of merit should be established for these components to provide a basis for comparison in evaluating the performance of given system functions.

(3) Definition of the operating parameters of the light storage elements used in the polatron, the ferrotron, and the double activated phosphor matrix should be continued during this quarter. These characteristics will serve to indicate the various theoretical advantages and disadvantages when outlining a specific design plan.

(4) Investigation, both analytical and experimental, of a matrix light source should be continued.

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IV. MATERIAL STUDY

A. SUMMARY

During the past quarter the literature survey previously initiated to determine the capabilities of materials exhibiting phenomena which could be useful in an image transducing device was continued. In particular literature concerning ferroelectrics and materials exhibiting persistent internal polarization was searched to determine material characteristics.

The ferroelectric materials can be divided into four groups, three of which are less desirable than the fourth. The basis for this decision is that one or more of the important parameters specifying the materials, namely, the Curie temperature and spontaneous polarization, was found to be inadequate for an image transducer of the desired specifications. Several members of the fourth group give promise of satisfactory performance in such a system. In particular, barium titanate with its large spontaneous polarization of 78,000 esu and relatively high Curie temperature of 120°C appears to be a good choice of material. Furthermore, barium titanate is readily obtained in pure single crystal flat plates.

Many materials are found which exhibit persistent internal polarization, although it is somewhat difficult to predict exactly what materials will show the effect. In general a photoconductor of high dark resistance is a likely candidate, particularly if it contains a large concentration of deep traps for both types of charge. The presence of a high dark resistance insures the absence, or at least low concentration, of shallow traps which tend to destroy the persistent polarization effect. A large number of materials appear to satisfy these criteria as they

exhibit a rather pronounced persistent polarization. Anthracene and K zinc cadmium sulfide show an especially strong effect, with polarizations as large as 10^{-7} coulombs/cm^2 possible. An additional feature of the effect is that decay of the polarization takes place very slowly allowing memory times as long as several days.

The experiments on hackmanite reported in the previous reports have been continued. Improvement in the properties of the hackmanite-bearing KBr wafers has been achieved. The use of naturally occurring hackmanite does not appear sufficient to meet the image transducing requirements, hence efforts are now being directed towards the development of a suitable synthetic hackmanite. The semicarbozones suggested by the previously reported literature survey on phototropic materials were also experimentally investigated. Several materials of this type were found to exhibit phototropic behavior but all suffered from a serious fatigue effect. In addition, the sensitivities were relatively low, hence these investigations were discontinued.

B. LITERATURE SURVEY

In the previous quarterly report the results of an extensive literature survey for photoconductors, double activated phosphors, electroluminophors, and phototropic materials was reported. At that time it was pointed out that in addition to these materials ferroelectrics are very important for application in an image transducing system. It was thus recommended that a survey of ferroelectrics be made. The results of that survey are reported in this section.

During the third quarter a phenomenon not previously considered was found to hold promise for application in an image transducing system. This effect, known as persistent internal polarization, is the persistence of an optically induced electrical polarization in certain types of materials after the removal of the polarizing voltage. A survey of such materials was immediately initiated and the results are reported herein.

1. Ferroelectrics

A Ferroelectric is a material which exhibits a spontaneous volume electric dipole moment; that is, a material which even in the absence of an applied electric field has the center of positive charge displaced from the center of negative charge. All ferroelectric materials are also piezoelectric, but all piezoelectrics are not necessarily ferroelectric. A piezoelectric is a material which develops a potential difference across its ends when pressure is applied and vice versa.

Normally, materials exhibit ferroelectricity only at temperatures less than a certain critical temperature T_c called the Curie temperature. In some cases, however, there exists both a lower and an upper Curie temperature and the material is ferroelectric only at temperatures between these two critical temperatures. Above the Curie temperature a ferroelectric behaves as an ordinary dielectric, while below the critical temperature the saturation polarization increases rapidly with electric field approaching a limiting value.

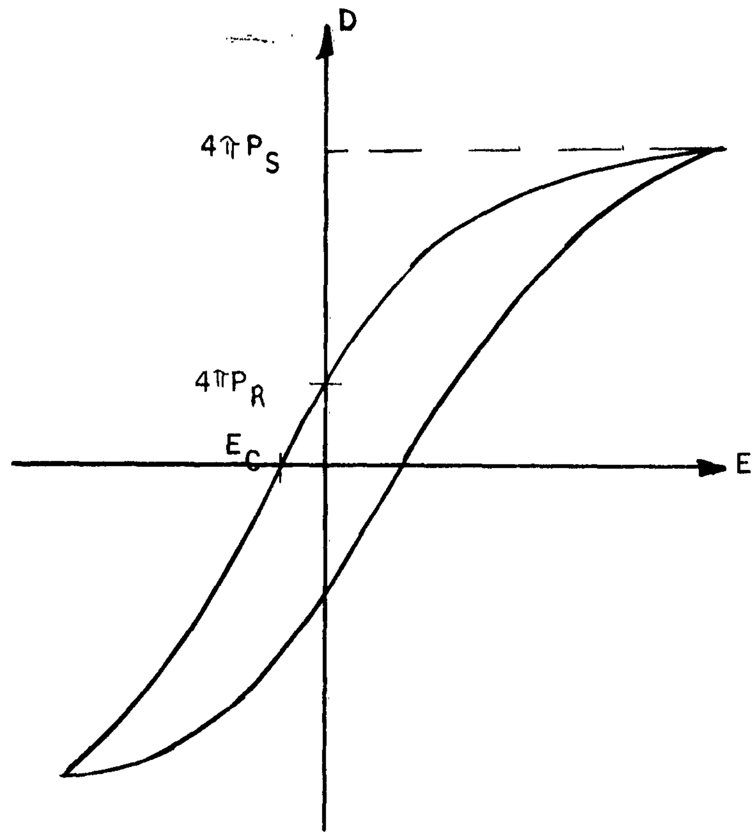
Ferroelectrics are characterized by a non-linear and non-reversible relationship between electric field strength E and electric displacement D. These two quantities and the polarization are connected by the equation,

$$\vec{D} = \vec{E} + 4\pi \vec{P}$$

using electrostatic units to measure the various quantities. A typical curve of D vs. E is shown in Figure 17. This is referred to as the hysteresis loop and is characterized by two important parameters, P_s the spontaneous polarization and E_c the coercive field. Additional parameters are sometimes introduced to give a measure of the "squareness" of the hysteresis loop, as this is of special interest for operation in a bistable mode, much the same as in the analogous case for ferromagnetic materials. One such parameter is the remanent polarization P_r indicated in Figure 17. The ratio of P_s to P_r clearly gives an indication of the squareness of the hysteresis loop.

The ferroelectrics presently known can be classified according to their chemical composition and crystal structure so that they fall into four groups. These four groups are listed in Table II. Group A includes the tartrates or rochelle salts in which ferroelectricity was first observed by Valasek.[1] The dihydrogen phosphates and arsenates of the alkali metals[2] make up group B. In group C are included the ferroelectrics with the perovskite and ilmenite crystal structures, sometimes referred to as the oxygen-octahedra[3] group. A large number of materials either isomorphic with guanidine aluminum sulfate hexahydrate[4] (GASH) or simply hydrogen bearing are included in group D.

TYPICAL HYSTERESIS LOOP FOR A FERROELECTRIC



P_S -SPONTANEOUS POLARIZATION

E_C -COERCIVE FEILD

FIGURE 17

TABLE II

FERROELECTRIC MATERIALS

Group	Crystal	Structure	T_c (°K)	P_s (esu) at room temp.
A	$NaK(C_4H_4O_6)\cdot 4H_2O$ (Rochelle salt)	complex	297 (upper) 255 (lower)	800
	$NaK(C_4H_2D_2O_6)\cdot 4D_2O$		308 (upper) 251 (lower)	1,100
	$LiNH_4(C_4H_4O_6)\cdot H_2O$		106	630
B	KH_2PO_4	complex	123	16,000
	KD_2PO_4		213	27,000
	RbH_2PO_4		147	
	RbH_2AsO_4		111	
	KH_2AsO_4		96.5	
	KD_2AsO_4		162	
	CsH_2PO_4		160	
	CsH_2AsO_4		143	
	CsD_2AsO_4		212	
C	$BaTiO_3$	perovskite	380	[illegible]
	$KTaO_3$	perovskite		
	$NaTaO_3$	perovskite	913	
	$KNbO_3$	perovskite	708	80,000
	$PbTiO_3$	perovskite	763	
	$LiTaO_3$	ilmenite		70,000 (425°C)
	$LiNbO_3$	ilmenite		
	WO_3	perovskite modified	(220) (?)	
	$Cd_2Nb_2O_7$	pyrochlorite	185	5,400 (100°K)
D	$C(NH_2)_3Al(SO_4)_2\cdot 6H_2O$	complex		1,050
	$C(NH_2)_3Cr(SO_4)_2$			1,000
	$C(NH_2)_3Ga(SO_4)_2$			1,000
	$C(NH_2)_3Al(SeO_4)_2$			1,350
	$C(NH_2)_3Cr(Se)_4)_2$			1,400

At present no single theory is able to successfully explain the ferroelectric behavior of all four groups of materials, rather different theories are required to explain the characteristic behavior of each of the four groups. Some success, however, has been achieved in specifying the necessary conditions for ferroelectricity. These are usually related to order-disorder theories, suggesting that ferroelectricity is the result of a cooperative interaction much the same as ferromagnetism and superconductivity.

Examination of Table II shows that both group A and D ferroelectrics have low values for the spontaneous polarization in comparison with those in groups B and C. It should be noted that deuteration greatly enhances the spontaneous polarization and increases the Curie Temperature of the dihydrogen phosphates of group B. The ferroelectrics of group B show very low transition temperatures even when deuterated. The group C ferroelectrics appear to have the largest spontaneous polarizations and, in fact, also exhibit very high transition temperatures. Barium titanate is characteristic of the group C materials and is one of the better understood ferroelectrics. In addition to having favorable values of P_s and T_c, barium titanate is readily obtained in single crystal platelets. Application to parallel plate capacitors is thus accomplished easily. Two dimensional matrix arrays can also be produced with a minimum of effort since the crystals are naturally grown in this plate-like structure. Experiments also indicate that the hysteresis loop for barium titanate can be quite square. This permits the use of barium titanate crystals for information storage devices.

The ferroelectric required for use in the ferrotron described in the Second Quarterly Progress Report should have a high spontaneous polarization P_s, a Curie Temperature well above room temperature, a reasonably square loop, and be available in flat, single crystal plates. From Table II and the discussion above, it is apparent that barium titanate satisfies all these conditions very well. Some of the other materials in group C satisfy the conditions for large P_s and high T_c but information is lacking concerning the squareness of the corresponding hysteresis loop and the availability of flat, single crystal plates. Further investigations of these materials may prove fruitful.

2. Persistent Internal Polarization Materials

The application of a DC electric field to a photoconductive, fluorescent substance of high dark resistance during irradiation results in an internal electric polarization which will persist after the removal of the radiation and electric field. This phenomenon is referred to as persistent internal polarization (PIP). Although the effect was recognized in the early 1930's, the first definitive work was reported by Kallmann and Rosenberg[6] in 1955. Since then many investigators have been active in the field. Kallmann[7] et al. reviewed the state of knowledge of the PIP effect in 1961.

In the original investigations of Kallmann and Rosenberg several sulfide phosphors and organic phosphors were examined to determine if there were any relation between the PIP effect and photoconductivity and fluorescence. The results of this investigation are tabulated in Table III. Although there does appear to be a direct relationship between photoconductivity and the PIP effect, no such relationship is apparent between the PIP effect and fluorescence. Of the materials listed in Table III, the zinc-cadmium sulfide identified as K and anthracene proved to be most satisfactory for observation of the PIP effect. Both are capable of maintaining polarization field

TABLE III

MATERIALS FOR PIP

SUBSTANCE	FORM	PRONOUNCED PIP	PRONOUNCED PHOTOCONDUCTIVITY	PRONOUNCED FLORESCENCE
K (Zn:CdS)	Powder	Yes	Yes	Yes
M (ZnS)	Powder	Yes	Yes	Yes
N (ZnS)	Powder	Yes	Yes	Yes
L (Zn:CdS)	Powder	Yes	Yes	Yes
LG 2150 (ZnS)	Powder	Yes	Yes	Yes
Anthracene	Powder	Yes	Yes	Yes
Anthracene	Fused Polycrystal	Yes	Yes	Yes
Anthracene	Single Small Crystal	Yes	Yes	Yes
Fluoranthene	Fused Polycrystal	No	No	Yes
Chrysene	Powder	Yes	Yes	Yes
9 - Bromoanthracene	Powder	Yes	Yes	No
Trans-stilbene	Single Large Crystal	Yes	Yes	Yes
ZnS - nonactivated	Powder	No	No	No
CdS - nonactivated	Powder	No	No	No
Paraffin	Fused Sample (thin)	No	No	No

gradients of more than 10^4 volts/cm over extended periods of time. Upon discharge of the polarization, output voltages in excess of 100 volts are obtained.

A typical specimen is illustrated in Figure 18. A transparent electrode is deposited on a glass substrate. The phosphor, usually in powdered form but occasionally in the form of flakes or a single crystal, is then placed upon the conducting surface and a second conducting surface, normally a metal foil, is placed upon it. For substances in the form of a fine powder, the samples are prepared by sedimentation from solutions of cellulose nitrate in amyl acetate. The layers are of the order of 0.1 mm thick. In the case of specimens in the form of fused solids or single crystals, layers from 0.05 to 0.3 mm are used.

Two methods are used to measure the persistent internal polarization of the specimen. One of these, the radiation discharge method is a non-repeatable process as it destroys the polarization at least partially. The other method, the lifted electrode method permits repeated measurement without appreciably reducing the polarization. In the radiation discharge technique the polarized specimen is connected to the grid of an electrometer tube and irradiated. Upon irradiation the polarization is destroyed and a voltage pulse is fed to the grid of the electrometer tube. This produces an output voltage pulse at the plate proportional to the polarization stored in the specimen. In the lifted electrode method the upper electrode is physically removed from the presence of the specimen thus trapping the image charge induced on the electrode by the polarization of the specimen. This charge is then fed into the grid of the electrometer tube producing an output voltage pulse

TYPICAL PIP SPECIMEN

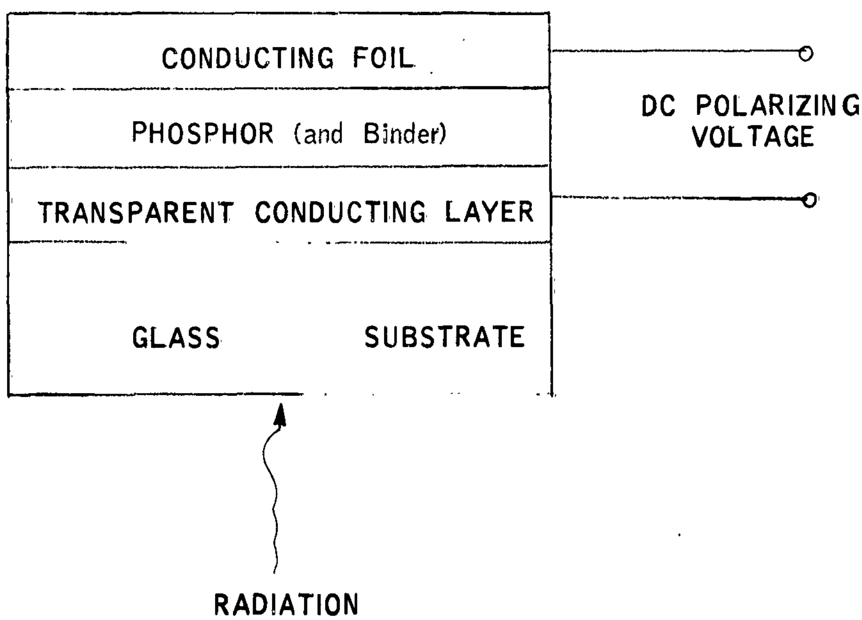


FIGURE 18

at the plate proportional to the polarization of the specimen. This process can be repeated as there is very little effect on the polarization of the specimen by physically removing the electrode. This latter method of polarization measurement may not be applicable for image transducing, however.

The persistent internal polarization effect can be understood on the basis of the energy band model for a phosphor. The exciting radiation raises electrons from the valence band to the conduction band. If a DC voltage is simultaneously applied, charge separation will be accomplished as the negative electrons will be urged in one direction and the positive holes in the opposite direction. Since the phosphor contains various types of trap levels, the charges will be trapped inside the specimen and current injection will not occur. This can be shown experimentally by insulating the phosphor from the electrodes by insertion of mica sheets. Experiments done in this way produce results no different from those previously described (except, of course, for the usual dielectric effect), hence current injection does not occur.

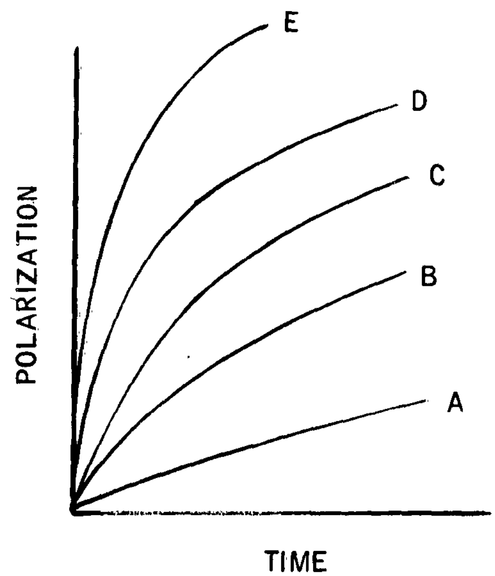
When the voltage and radiation are removed the charges remain in the trap for the lifetime of the trap state. This varies with the temperature and degree of irradiation of the specimen. If the specimen is maintained in the dark and the temperature is not excessive, the lifetime can be many hours or even days. The normal decay curves appear to contain a small very rapid decay component and a large very slow decay component. Subsequent irradiation of the specimen frees the trapped charges which then move so as to cancel the polarization field. This results in a voltage pulse across the sample, which serves as the output signal.

The initial fast decay of the polarization can be explained by the presence of shallow traps while the long decay portion can be explained by the presence of deep traps. Clearly, the presence of deep trap states is essential for the persistent internal polarization, while the presence of shallow trap states tends to destroy the long persistent internal polarization. It is, therefore, desirable to obtain samples with a small number of shallow trap states and a relatively large number of deep trap states. Such specimens exhibit very high dark resistance, even at room temperatures. This provides a negative criterion for choosing a material to exhibit the PIP effect in that materials of low dark resistance are eliminated but materials of high dark resistance do not necessarily exhibit the PIP effect.

It is also observed that the presence of trap states for one type of charge alone is insufficient to produce persistent polarization. The reason for this is that the charges for which no traps exist are free to move about and destroy the polarization by recombining with the localized charge once the external polarizing field is removed.

The polarization is found to increase exponentially to a saturation value which is dependent upon the trap density in the specimen. The rate of buildup of polarization is a strong function of the intensity of the incident radiation. Typical behavior is indicated in Figure 19 where the intensity of the incident radiation increases from curve a alphabetically to curve e. These curves are all plotted using the same polarizing voltage since the polarization is a function of the polarizing voltage. There appears to be a linear relationship between polarization and polarizing voltage over a considerable voltage range.

TYPICAL POLARIZATION BUILDUP
WITH VARYING INTENSITY OF INCIDENT RATIATION



THE INTENSITY OF INCIDENT RADIATION
INCREASES FROM CURVE A TO E

FIGURE 19

C. EXPERIMENTAL INVESTIGATION

1. Hackmanite

Because of the large amount of light required to generate and erase the pink coloration in hackmanite, it has been considered unsuitable as the data storage material for a high sensitivity image transducer. However, because of the complete absence of fatigue upon many thousand repetitions of the color generation and bleaching cycle, and because of the desirable spectral characteristics, it is a promising material for low sensitivity applications. Accordingly, investigational efforts have been directed towards producing hackmanite in a thin transparent layer with a uniform sensitivity distribution in a planimetric sense. The previous report described an experimental program to utilize the combination of high temperature and high pressure coupled with chemical and electrical procedures to improve the transparency and sensitivity of natural hackmanite. Although progress has been impeded by unexpected equipment troubles centered around the 50 ton vacuum hot press, increasingly clear sample discs of the KBr matrix have been prepared, some of them as thin as 1/16 inch. Further experiments were made to incorporate natural hackmanite into the KBr matrix. This has been accomplished but complete transparency has not been obtained due, most probably, to the optical inhomogeneity of the natural hackmanite. A typical experiment consisted of mixing 25 parts (by weight) of powdered hackmanite with 75 parts of KBr and heating in the vacuum hot press at 600°F and 5×10^{-4} microns for one hour. This was followed by pressing at 50,000 psi and cooling under pressure. The resulting wafer under ultraviolet excitation showed hackmanite's typical orange fluorescence but the pink coloration was indiscernable because of the low concentration of color centers. As the attempts to modify naturally occurring hackmanite to fit the image transducer requirements have not been altogether satisfactory, work is currently being directed towards producing a synthetic hackmanite in a thin transparent layer of uniform sensitivity. This requires the mixing of the chemical constituents of hackmanite prior to the heat and pressure treatments. Since the components may be intimately mixed and ground together, the attainment of a layer of uniformly sensitive properties is greatly facilitated. In addition, the concurrent control over the proportions of the constituents makes possible the systematic evaluation of each component thereby increasing the possibilities of improving the absolute sensitivity of the basic material. This might be further enhanced by controlled introduction of specific impurities directed towards increasing the concentration of color-center sites. The use of electrical field and high current densities during various phases of the heat and pressure treatments is also under consideration.

To provide a reference basis it is planned to measure the absolute sensitivity of the naturally occurring hackmanite. The necessary light sources have been fabricated and as soon as the high sensitivity measuring equipment is obtained these measurements will be undertaken.

2. Semicarbazones

As reported in the Second Quarterly Progress Report, the literature survey for phototropic materials revealed that cinnamaldehyde semicarbazone and some of its derivatives show phototropism. These materials are phototropic in a reverse manner, i.e., instead of generating a color upon being irradiated with an activating light, they showed no color change upon activation but upon placing the activated sample in the dark a color change slowly took place. The generated color is bleached out when the sample is illuminated with white light, and it is claimed that the cycle of color generation and bleaching can be repeated indefinitely. These results were reported during the period from 1914 to 1923. In the modern work with phototropic organic compounds one of the major drawbacks to the use of these materials in image transducer applications is the tendency for rapid fatigue, i.e., the progressive loss of phototropic properties on successive cycles due to an increasingly large amount of the active material being converted into non-active side products. Hence, if the semicarbazones were not subject to fatigue, thereby constituting an exception to the general rule, it is worthwhile to examine them in the light of modern day techniques and equipment. Accordingly, an experimental program was undertaken to fabricate them and determine their phototropic properties.

First, lists of organic chemicals were scanned for suitable intermediates for synthesizing the most promising of the semicarbazones. A number of these were obtained and the corresponding semicarbazones were synthesized. These were then tested for phototropism using the same procedure described by the original investigators with cinnamaldehyde semicarbazone. This consisted of exposing the material to bright sunlight for four hours then placing it in the dark overnight. Pure cinnamaldehyde semicarbazone as it is first synthesized is a white crystalline material. If it is placed in the dark without prior exposure to sunlight nothing happens; it remains pure white.However, after exposure to sunlight the material when placed in the dark develops a yellow coloration. Upon exposure to light it gradually reverts to the colorless form at a speed dependent upon the intensity of the light. Upon placing it in the dark the yellow color is again generated, and in light again bleached. The synthesized semicarbazones were tested in this manner to confirm the results obtained by the original investigators with the cinnamaldehyde semicarbazone and to compare the latter with the newly synthesized materials. The results are listed in the following table:

Material: Semicarbazone of	Color	Phototropic Behavior
1. Cinnamaldehyde	white	good
2. -methyl cinnamaldehyde	white	none
3. 2- Furaldehyde	brown	irreversible color change
4. Citral	white	none
5. Salicylaldehyde	white	very slight
6. Piperonal	white	none
7. 5-nitrosalicylaldehyde	pale yellow	irreversible color change
8. 1,5-Bis (p-methoxyphenyl) -3-pentadienone	deep yellow	irreversible color change

It is possible that some of the compounds which gave no visible indication of phototropism may nonetheless be phototropic with the absorption occurring in the ultraviolet part of the spectrum. This possibility might be worth investigating. However, even though phototropic behavior was easily obtained with the cinnamaldehyde semicarbazone, it was found that fatigue gradually took place and attempts using various purification techniques to prepare a sample that did not fatigue were not successful. Since the absolute sensitivities of these compounds are very low, further work along these lines was discontinued.

D. RECOMMENDATIONS

The material study has supplied sufficient information on electroluminophors, photoconductors, double activated phosphors, ferroelectrics, persistent internal polarization materials and phototropic materials to warrant institution of further experimental investigations to determine the best of the various types of materials and the optimum operating configuration and conditions. During the next quarter the following areas should be emphasized:

(1) Determination of the most desirable ferroelectric and photoconductor combination for use in the ferrotron.

(2) Determination of the most desirable photoconductor for use in the polatron.

(3) Development of a synthetic hackmanite by variation of constituents and fabrication parameters.

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V. CONCLUSIONS

(1) The most promising element for an advanced image transducer is either the ferrotron, the polatron or the daptron.

(2) Experiments are required to obtain quantitative photometric performance data of these elements.

(3) Image readout can be effected by use of either a matrix scan or a line scan. The choice of readout method is dependent to a large extent upon the performance characteristics of the specific image transducer element.

(4) The use of the optron element for image transducing is not advisable because of its lack of resolution capability.

(5) The feasibility of the ferrotron as a possible image transducing element is established inasmuch as a short exposure and readout time and erasure capability has been experimentally demonstrated.

VI. PROGRAM FOR NEXT INTERVAL

A. SYSTEM ANALYSIS

System analysis will proceed to further delineate transducer requirements and limitations. This analysis together with the results of the component research will further specify the design criteria of the system. The outcome of this effort will be a comparison of various promising design configurations. The evolved configurations will be presented in a design plan.

B. COMPONENT RESEARCH

Laboratory experimentation will be carried out to determine the relative merits of the three most promising image transducing elements, namely: (1) the ferrotron; (2) the polatron; and (3) the daptron. This laboratory work will be guided by the results of the material study. The experiments will also provide quantitative data on such parameters as sensitivity, spectral response, quantum efficiency, image retention, resolution, etc.

The analysis of concepts for image transducing elements and readout methods utilizing the results obtained in the experiments will be continued.

C. MATERIAL STUDY

Analytical and experimental investigations to select image transducing materials for further development will be continued. This investigation will include an evaluation of the materials suitable for application to the ferrotron and the polatron. In addition, further experiments will be conducted with synthetic hackmanite.

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